Volume

1

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NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES

VOLUME 1

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NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES

VOLUME 1

By

JACQUES, WHITFORD AND ASSOCIATES LIMITED

With

P. LANE AND ASSOCIATES LIMITED

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EXECUTIVE SUMMARY

This report, prepared for Energy, Mines and Resoures by Jacques, Whitford and Associates Limited reviews and presents non-combustible replacement materials, methods, and techniques to reduce the usage of wood in coal mines and assesses the fire risk. The document represents the culmination of several months of literature searches, data compilations, and computer modeling.

The use of wood in the coal mines represents a significant fire hazard because of the large fuel load it presents as well as the continous flame path it creates through extensive areas of the mine. The risk of fire in the CBDC coal mines would be greatly reduced if the use of wood could be minimized. Longwall mining methods were the focus of this study as it is considered the "worse case" situation for wood usage.

The first phase of the study developed a fire risk assessment of the extensive volume of wood used in the coal mines. A large fault tree model, a deductive methodology based upon Boolean algebra, was constructed for a longwall mine. It begins with the definition of an undesirable top event, a mine fire, and proceeds to diagram all important causal pathways of events leading to the fire. The qualitative model was developed around four major areas of the mine: working panel, main entry tunnel, developing area, and abandoned area. Combustible materials were considered to be of three types: mixtures of methane gas and airborne coal dust, loose coal and accumulated coal fines, and imported flamable materials such as fuels, explosives, cloth, plastic, paper, and wood.

Although analysis of the model is limited without quantitative data, preliminary reviews indicated that wood was a potentially significant contributor to approximately one third of 857 file causal pathways of the model. It was concluded from this work that fault tree analysis can be successfully applied to mine fire risk assessemnt and that the model should be developed to produce a quantitative risk analysis.

The second phase of the study reviewed technologies for wood replacement in underground coal mines and evaluated the use of indigenous materials for these roles.

The current applications of wood in CBDC coal mines were identified, including construction materials, gateside packs, roadway lagging, cavity stabilization, remedial support, rail ties, and face-line development. Alternate materials and technologies which could be used to replace these uses of wood such as stowing methods and fly ash cements were also reviewed.

The priority for wood replacement was established employing a predictive fire risk index founded upon the fault tree risk assessment developed in Phase I. The wood replacement priority, in descending order of importance is as follows: lagging, wooden packs, cavity filling materials, construction material, rail ties, and remedial support members.

Fly ash and anhydrite, both readily available in Cape Breton, were identified for use in gateside packs, cavity fillings, and construction materials. Other recommendations included coating standing timber with a mine sealant, replacing wood lagging with welded wire mesh panels, and using shotcrete or gunite as a roadway lining.

Résumé des recommendations

Cet étude a été préparé par la compagnie Jacques, Whitford & Associates Limited pour le Ministère de l'Énergie, mines et ressources Canada. On a fait l'étude des matériaux incombustibles étant capables de remplacer le bois, les méthodes et les techniques servant à réduire l'usage du bois dans les houillères, ainsi que l'évaluation du risque d'incendie. L'étude rassemble tous les données, la recherche de la documentation, et le computer modeling obtenus pendant plusieurs mois.

Dansl'industrie houillère, le bois devient un grand risque d'incendie à cause de sa capacité en tant que combustible et quand le bois crée un trajet de feu qui traverse le réseau souterrain de la mine. Donc, le risque d'incendie dans les houillères de la Société de développement du Cap-Breton serait réduit considérablement en minimisant l'usage du bois. Étant donné que la méthode d'exploitation minière de front de taille (longwall mining method) est considérée comme une des méthodes les plus problématiques pour l'usage du bois, ce rapport a seulement fait l'étude de cette méthode.

Eu premier lieu on a évalué le risque d'incendie dans les houillères d'après l'étendue de bois utilisé. Par la suite, on a rédigé un modèle «fault tree», une méthodologie déductive basée sur l'algèbre Boolean, proprice à l'exploitation minière de front de taille. Le modèle établit, d'après la définition de l'événement initial tel qu'un feu à l'intérieur de la mine, un schéma de toutes les étapes qui conduisent au feu.

Le modèle a été développé avec l'aide des quatres endroits principales de la mine: le front de taille, l'entrée de galerie principale à flanc de coteau, le district minier en voie de développement, ainsi que le district minier abandonné. Les matières combustibles classées d'après trois types comprenaient: un mélange de méthane et de poussier aéroporté; le charbon et les accumulations de particules fines de charbon; ainsi que les matières inflammables provenants de l'extérieur telles que les carburants, les explosifs, le linge, le plastique, le papier et le bois.

Malgré une analyse quantitative limitée à cause d'un manque de données, l'étude préliminaire a démontré que le bois contribuait à approximativement un tiers des 857 causal pathways importantes du modèle.

On a donc pu conclure d'après ce travail que le modèle fault tree peut être employé avec succès à l'évaluation du risque d'incendie à l'intérieur d'une mine, et pourrait même être développé pour comprendre une analyse quantitative de ce risque d'incendie.

La deuxième étape de l'étude mena une analyse des technologies visant à remplacer le bois dans les houillères souterraines tout en comprenant le rôle des matières autochtones dansce domaine.

L'usage actuel du bois dans les mines de charbon appartenant à la Société de développement du Cap-Breton en somme comprend le bois comme matériel de construction, comme remblais de voie de roulage, garnissages de route, stabilizations de cavité, soutènements traverses, dans le développement de tailles chassantes. De plus, le bois pourrait être employé dans les méthodes de remblayage et en tant que ciment fly ash.

Tou ces usages ont été étudiés dans ce rapport.

On a également obtenu un indice à risque d'incendie fondé sur l'évaluation du risque développé d'après le modèle fault tree durant la première étape. Cet indice a pour suite établit les priorités dans le remplacement du bois. Les priorités en ordre d'importance sont comme suit: le garnissage, les remblais, les matériaux pour remblissage de cavité, les matériaux de construction, les traverses et le soutènement correctif.

Le fly ash et l'anhydrite sont abondants au Cap-Breton et l'étude les a considérés pour leur usage en tant que remblais de voie de roulage, dans le remblissage de cavité, et comme matériel de construction. On recommende également leur emploi dans l'ignifuge du bois, dans le remplacement du garnissage par les panneaux de grillage, et en utilisant le shotcrete ou le gunite comme matériaux de revêtement routier.

PREAMBLE

Background and Project Rationale

The Sydney coalfield is situated in northeastern Nova Scotia, on and offshore Cape Breton Island. It consists of two sectors: a small land area (520 km^2) and a large offshore region. Both areas form a large Carboniferous basin which extends towards Newfoundland, occupying in the order of 36,000 km^2.

The Sydney coalfield contains the largest coal reserve in Eastern Canada, 98 percent of which is submarine as the coal seams dip gently approximately 5° seaward. The coals are ranked as high volatile A bituminous (Hacquebard, 1983) but are medium volatile bituminous in zones.

The Cape Breton Development Corporation (CBDC) operates two collieries in the Sydney coalfield, the Lingan and the Prince on the Harbour and Hub seams, respectively. A third colliery, the new Phalen mine is presently being developed and should commence production in the year 1987. The anticipated output of the Phalen in 1988 will be in the order of 1.4 million tonnes. The Donkin Mine, which is not as yet producing, is not expected to begin operations until the 1990's.

The CBDC currently produces in the order of 2.7 million tonnes of coal annually and employs in excess of 3000 personnel directly (NSDME, 1984).

Large volumes of wood are utilized in underground coal mines in a variety of roles, such as, mine supports, permanent and temporary structures, rail ties, doors. The use of wood is considered to be costly to supply, and manual placement techniques are expensive. Historically, wood presented minimal fire hazards as the mine operations were typically labour intensive, using hand tools and pneumatic equipment which were limited sources of ignition. The quantities of wood presently used in the mines, however, is virtually unchanged even since the introduction of extensive electrical and mechanical equipment has increased the potential for ignition of the wood.

The rapid spread of coal mine fires may be attributed to the use of wood in coal mines and close proximity of the sources of ignition. The Cape Breton collieries have experienced underground fires, of varying degrees of severity; the most recent and disastrous of which resulted in the permanent closure of the No. 26 Colliery and loss of life.

Current research work is being performed to reduce the dependence on wood; thereby reducing the incidence of fire. It is within this context that Jacques, Whitford and Associates Limited were awarded a contract to assess the relative fire risks encountered in the various segments of the CBDC collieries and to review the non-combustible alternatives and substitutes for wood in the mine operation, including potential indigenous sources of replacement materials. The terms of reference for the study were outlined in the statement of work which has been attached as Appendix 1.

Study Participants

The contract was awarded by Supply and Services Canada in May, 1985, under the direction of Mr. G. A. Haslett, P.Eng. of the Cape Breton Coal Mine Research Laboratory (CBCMRL). The prime consultant Jacques, Whitford and Associates Ltd. assigned Mr. John Amirault, M.Eng., P.Eng., as project manager. The key personnel participating in the project were as follows:

- Jacques, Whitford and Associates Ltd. (JWA)
  Mr. D.S. Jones, P.Eng., MBA - Mining Engineer
  Mr. C.G. Sheppard, B. Eng. - Mining Engineer

- P. Lane and Associates (PLA)
  Dr. P. Lane - Senior Systems Analyst
  Mr. J.A. Wright - Systems Analyst

P. Lane and Associates Limited performed the risk assessment of underground fire in Cape Breton coal mines, using deductive fault tree analysis, entailed the construction of a large qualitative fault tree model of four areas in the longwall mine. Computer techniques were utilized for the construction of the model.

Jacques, Whitford and Associates Limited investigated the alternative technology and techniques suitable as a non-combustible wood substitute and also reviewed the sources of raw materials, indigenous to the region, which could be utilized in wood substitutions. This work was undertaken in two parts. The first of which gathered technical information from manufacturers, suppliers, mining companies using the technology, and finally research groups such as CANMET, NCB, MRDE and USBM. Several computer literature searches were performed so as to obtain data on the current trends in industry and research.

Upon the identification of wood alternative techniques applicable to the CBDC coal mines, indigenous sources were sought, which could provide the necessary raw materials for the manufacture of these products. Data was collected through communication with local producers of limestone, gypsum, anhydrite, coal and mineral wastes as well as the Nova Scotia Department of Mines and Energy (NSDME).

Report Organization

The report is presented in two phases.

Volume I contains Phase I - Risk Asessment of Underground Fire in Cape Breton Coal Mines.

Volume II contains Phase II Part I - Wood Substitute Investigation, and
Part II - Review of Indigenous Materials

This preamble accompanies each volume and contains a complete Table of Contents for the entire report.

The document has been structured so that any Phase or Part can be extracted and used in its entirety, separate from the remaining portions of the report.

Phase I is presented in five sections. Details discussed include an introduction to fault tree analysis, a description of the model and a discussion of the results.

Phase II is presented in nine and ten sections for Parts I and II, respectively. Part I discusses the various wood substitute technologies which are available and currently used by the coal mining industry; including gateside packwall supports, cavity filling techniques, and new face development. Part II presents the sources of indigenous materials used in the technologies discussed in Part I and includes mineral aggregates, limestone, gypsum/anhydrite, etc. An evaluation of the cost of these materials is presented. We have also prioritized the areas of wood replacement.

Respectfully submitted,

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NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES.

PHASE I: RISK ASSESSMENT OF UNDERGROUND FIRE IN CAPE BRETON COAL MINES

By P. LANE AND ASSOCIATES, LTD.

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PHASE I

RISK ASSESSMENT OF UNDERGROUND FIRE IN CAPE BRETON COAL MINES

By

JACQUES, WHITFORD AND ASSOCIATES LIMITED

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SUMMARY

Coal mines present high occupational risks for their workers. In particular, the risk of fire is always present and it constitutes a major source of worker fatality throughout the world. A specific problem is the extensive use of wood in coal mines; it is easily combustible and thus, constitutes a definable and critical hazard.

Risk assessment techniques, both inductive and deductive, are becoming increasingly used in manufacturing and energy-related industries. The fault tree analysis is a deductive methodology based on Boolean algebra. It begins with the definition of a top event which is undesirable and proceeds to diagram all important causal pathways of events leading to that top event. Fault trees are used routinely in the nuclear industry, however, for coal mining, their use has been very restricted and fairly esoteric. Because of the high level of human-machine interaction in coal mines, they are especially complex and difficult to model.

In this study, a large fault tree model with 520 distinct primary events has been constructed for a longwall type of mining operation typical of those in Cape Breton, Nova Scotia. The model is purely qualitative but has been designed for future quantification and for wide practical application. The top event is the initiation of fire anywhere in the mine in any combustible material.

The model is developed around four areas of the mine: working panel, main entry tunnel, developing area and abandoned area. The working panels are further divided into faces, intakes, returns and gob areas. Combustible materials are considered to be of three types: mixtures of methane gas and airborne coal dust, loose coal and accumulated coal fines, and imported flammable materials, which would include wood along with other materials such as fuels, explosives, cloth, plastic, paper and so on. It is quite possible to expand the model to specifically deal with other spatial categories and classes of combustible

materials.

Although analysis of the model is limited without quantitative data, a small example based on the model is presented and discussed as to how the model could be analyzed. Further, an outline for future development and application is provided. It is described here how fire initiation and propagation in wood could be examined.

Preliminary analysis indicated that wood was a potentially significant contributor to the top event of fire in the mine. As the major constituent of the imported flammable materials classification, it is involved in approximately one third of the 857 causal pathways of the model.

The major conclusions of this report are that fault tree analysis can successfully be applied to specific and general problems of fire safety in the coal mining industry and that the model presented here should be further developed to produce a quantitative risk analysis.

NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES.

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1.0 INTRODUCTION

1.1 Risk of Fire in Coal Mines

Underground coal mining is one of the most dangerous of all occupations. A major risk is uncontrolled fire and all of its ramifications. Underground coal miners have very limited means of escape and a similarly limited air supply. An underground fire can easily cut off all escape routes and cause loss of life. The fire can also pollute the air supply of other parts of the mine with toxic combustion products and decrease oxygen concentrations below minimal levels. A key hazard is the presence of methane gas, which in combination with oxygen and coal dust in the air supply can be extremely explosive. Another hazard in some mines is the possibility of spontaneous combustion of coal.

The overall structure of a mine, with long narrow tunnels and air flow in one direction encourages the rapid spreading of a fire through the tunnels. Controlling the fire can be very difficult and dangerous if the only approach is from downwind. Nova Scotian mines have been involved in several serious fires and explosions with resultant loss of life.

Besides the risks to human safety, mine fires can lead to severe economic consequences such as loss of equipment, production time and so on. In the extreme, the loss of the whole mine for future production is a possibility, because if the fire cannot be extinguished, the mine must be closed down and sealed off.

There are three prerequisites to the initiation of fire: the presence of oxygen, a source of heat and a combustible material. All three components of the fire triangle are present in a coal mine in an array of combinations. Oxygen as a prerequesite for combustion is also a requisite for life. Thus, mines must be well oxygenated if miners are to work in them.

Sources of heat for ignition are numerous although every attempt is made to limit them. The very act of shearing the coal away from the face causes a certain amount of incendive friction which can produce heat and sparks. The intrusion of certain types of stone into the coal seam can exacerbate this problem. A variety of other machinery and electrical cables can malfunction causing heat and sparks.

There are many types of combustible materials found in a coal mine. One of the most troublesome is wood which is used for a large number of purposes, but mostly as a structural material. Roof supports in open areas are often made by stacking blocks of wood, in a square column, known as a "pack". Wood is also used as "lagging" to line tunnel walls and ceilings, for equipment supports and housing, and to wedge arch supports against irregular tunnel surfaces.

This wood can be a ready source of fuel to a fire and provide a "flame-path" along the length of a tunnel which can help to spread the fire. Some measures have been taken to develop fire-proofing methods for wood in coal mines. In most of these methods, however, applicability is limited and in all cases, efficacy is debatable. These fire treated woods are not in current use in any Canadian mines.

1.2 Purpose of Study

The purpose of this part of the study is to examine the risks of fire posed by the presence of wood in an underground coal mine using a qualitative fault tree model. The conceptual basis for the model is the longwall type of mine in Cape Breton, Nova Scotia.

In this study, all aspects of fire initiation in an underground coal mine are analyzed and the causal event pathways leading to fire initiation are diagrammed. The model is further developed to show the event paths leading to a fire in wood.

1.3 Significance of Study

By determining where wood is involved in the causal sequences of coal mine fires and the places where wood represents the greatest fire hazard, mining methods can be modified to minimize risk and make the industry safer. In fact the model (when analyzed quantitatively) can help reduce fire risks of all kinds of fire in the underground mine.

The fault tree methodology itself is in a state of "technology transfer" to the mining industry. In other industrial applications, it has shown great power and usefulness, in particular, in the nuclear regulatory and chemical manufacturing industries. The successful use of fault tree analysis in this study represents an advancement for the science of reliability as well as mining safety.

1.4 Acknowledgments

We gratefully acknowledge the valuable assistance of Mr. J. Kochhar, P.Eng., Chief Mining Engineer for the Cape Breton Development Corporation, who shared his insights into the workings of the Cape Breton mines and also supplied needed data and other information. Discussions with Dr. Harold Nelson of the National Bureau of Standards and Dr. Jeff Welsh and Dr. F. Cohen of the U.S. Bureau of Mines greatly facilitiated the early parts of this study and provided us with valuable information. Drs. Tanya and Lev Ginzburg advised us on the quantitative methodologies for fault tree analysis and how it has been used in other industrial applications.

2.0 METHODOLOGY

2.1 Overview of Inductive and Deductive Risk Assessment Techniques

All the methods considered in this study come from the general area of systems analysis. This is the formal study of systems and their functioning, be they mechanical, chemical, economic, or mathematical abstractions. It has been developing as a distinct field since the 1940's, mainly in conjunction with the engineering and mathematical sciences. The sub-disciplines of systems safety analysis and reliability analysis focus on how systems malfunction, what the consequences of such malfunctions are, and what hazards to life and property can result from the normal and abnormal operation of systems.

Recently, the term risk assessment has come into use to cover a wide variety of probablistic techniques in many fields which center on determining the likelihood of some undesirable event occurring.

Numerous methods have been developed and applied. Barlow, Fussell and Singpurwalla (1975) commented that mathematicians and statisticians working primarily in the field of reliability theory had proceeded along a parallel but distinct track from that of the engineers who developed safety analysis. The differing prespectives, one formal and rigorous, and the other practical and applied, coupled with a general lack of communication, had led to considerable overlap and confusion in the methodologies.

This situation has, to a great extent, been rectified in more recent years. In addition, the advent of computer technology has added a new dimension to the field and has substantially increased the scope and complexity of the problems that can be addressed. We have evaluated many techniques for safety/risk assessment by reviewing the literature pertaining to both general and specific (coal mine) applications.

Safety/risk assessment methods can be broadly classified into two categories: inductive and deductive. An inductive method postulates subsystem or component faults and determines the effects on the overall system. Deductive techniques are those that consider a specific failure of the overall system and investigate the component faults and/or events that could contribute to such a failure. Inductive methods answer the question: "What-happens if?"; whereas, deductive methods answer: "How can something happen"?. Battelle Pacific Northwest Laboratories (1983) gives a good introduction to both inductive and deductive risk assessment techniques and compares their pros and cons.

Many of the forms of risk analysis that we examined such as Preliminary Hazards Analysis (PHA) and Fault Mode and Effects Analysis (FMEA), are too general to be directly applicable in this study. PHA, for example, deals with all possible hazards within a system on a component-by-component basis. FMEA delineates the possible malfunctions of a given system component and the possible hazardous consequences in each case.

There are many different types of inductive methods, mostly depending on what level of information is available and what aspects of the event are being considered. For example, event tree analysis is an inductive, logic technique that sequentially models the progression of events, both successes and failures, leading from some initiating event like the breakdown of a piece of equipment to a series of logical outcomes. Nelson's (1981) unpublished study is based on an event tree model.

It is clear that in this study we are trying to determine the causes of a specific problem in a system (i.e. the causes of fire in a coal mine system). Therefore, the use of deductive methods are clearly indicated. Inductive methods would not be useful until it was desirable to focus on a specific system component and detail its possible hazardous aspects.

Fault tree analysis is the main deductive methodology used in system safety analysis. It evolved in the early 1960's in the aerospace and defence industries and has since found wide application in the chemical and manufacturing industries. Most recently, fault tree methods have been extensively used and developed in the nuclear energy field. Many fault tree models have been developed, some involving dozens of man-years of effort.

Fault tree analysis provides a systematic, descriptive approach to identification and control of hazardous conditions. It is a deductive logic technique that diagramatically models various combinations of basic failure events that could result in some overall failure event. Often event tree analysis is used as a preliminary tool prior to conducting a full fault tree analysis.

Fault tree models are qualitative in that they deal with relationships between events in terms of whether or not those events have occurred and may also consider the truth or falsity of certain conditions. Depending on the data base available and the level of description desired, fault tree models can be analysed in a variety of qualitative or quantitative ways. In the former case, the model is limited to being a diagrammatic representation of the system of interest and the model can be used to count, visualize, and understand the causal relationships of the hazards leading to the top event. With known probability values, many forms of quantitative analysis can be used to calculate the overall probability of the top event occurring and to assess the relative strengths of the various contributing branches of the tree to the occurrence of the top event.

Much of the information we have gathered on fault tree techniques concerns quantification of an existing tree and associated mathematical and computer sophistications. (Bennets, 1975, 1983; Bengiamin et al., 1976; Cummings, 1983; Lapp et al., 1977; Moret et al., 1984; Pullen, 1984;

Locks, et al., 1981; Schneeweiss, 1981; Wheeler et al., 1977). Little information or instruction exists to guide the initial system conceptualization and construction of a fault tree model.

Risk Assessment of Coal Mine Safety

The use of risk assessment techniques in the mining industry has been slow to develop. This is particularly unfortunate given the numerous hazards and high risks to human life associated with underground mining. For example, many more people have died in mines than have died in nuclear accidents. Mining operations are fairly complex systems to be modelled comprehensively and tend exhibit a relatively low degree of automation. For these reasons, mining is less amenable to formalized systems analysis methods than many other industries.

Most functions in a mine involve a human element, usually with each piece of equipment manipulated by one or more workers who are physically present with the machine. Thus, events in the system are difficult to predict. Moreover, there are extra levels of hazards to consider, both those associated with the unreliability of the human operators, and those associated with the systems required to support human life in the mine.

Finally, the consequences of equipment failures and unexpected events tend to be great because of the lack of fail-safe and backup systems, and of course, the direct threat to human life. Many mine disasters have been the result of low-probability, high-consequence accidents that are essentially unforseen combinations of events and conditions, which are individually relatively innocuous, but whose combination has had fatal consequences.

This is in contrast to the example of a nuclear power plant where most of the systems and operations are highly automated and thus, very predictable with well-defined points where faults can occur and disrupt normal operations.

The human operators are at the top of the control system and in many cases are only required to become involved in a problem situation. Also, there are automatic checks and backup systems which help control the effects of failures within the system. Finally, the simple fact that in most cases humans are physically isolated from the system, introduces an extra safety factor so that many faults do not have fatal consequences.

Whether owing to regulation or an awareness of the ultimate dangers inherent in the nuclear process, the nuclear industry has been very active in the development and application of safety asessment techniques and routinely use very sophisticated fault tree models. In contrast, the mining industry, tends to be more traditional and relies on direct, practical approaches. For the types of situations described above; however, this has not always been adequate.

Suggestions for the application of system safety methods in underground mining began to appear in the late 1970's. In 1982, the U.S. Bureau of Mines sponsored Battelle, Pacific Northwest Laboratories (1983) to conduct an extensive evaluation of safety assessment methods for the mining industry. Their report outlines several methodologies and makes recommendations as to which methods are directly applicable and which should be slated for "technology transfer" to the mining industry. Fault tree analysis (FTA) was given high priority in this report. The methodology of FTA is described in detail in "Fault Tree Handbook" (Vesely, 1981) produced by the U.S. Nuclear Regulatory Commission.

Most of the fault tree examples used for coal mines have been rather simple mechanical systems. For example, applications in specific mechanical sub-systems of the mine, such as operation of a piece of machinery or a ventilation system have been modelled. An entire mine represents a much more complicated system particularly in regard to fire hazards.

In this study, we are interested in a specific hazard, that of fire, and all possible circumstances which could lead to a fire. It appears that even with the best current methods, a great deal of intuition and insight is necessary to develop a fault tree model of a coal mine. The most useful preparatory step is to formulate a clear systematic description of the system under study.

Where more hypothetical systems or more general faults have been modelled, the treatment has usually been quite general, stressing, the theoretical aspects of the top event (Nelson, unpublished). Because the distinct environments where the event might take place are not specifically considered, this type of model is not directly applicable to a real-world situation. Also, such models tend to incorporate some fairly esoteric primary events for which it would be difficult or impossible to quantify event probabilities based upon existing data or past experience.

Two Specific Examples

Two models were reviewed which dealt with the risk of fire in a coal mine. A model developed by Denney et al., (1978), considered a specific mine and a specific event which resulted in numerous deaths as a result of an underground mine fire. The authors developed a model which calculated the probability of a fatality given the layout and conditions of the mine at the time of the accident.

The model considered factors which would prevent the trapped miners from continuing to breath in the event of a fire, and where they could breath, factors which would prevent them from escaping on their own or being rescued. The existence of the fire was assumed and not developed as a fault tree. In addition, the fact that the model assumed that: 1) all or most of the miners underground would be in a specific location; and, 2) the fire also occurred in a specific location greatly reduced the size of the model.

The authors estimated probability ranges for the primary events and calculated the range of probability of the top event which was the expected number of fatalities. High values were shown to result from the model of the accident scenario and the authors used the model to identify several critical conditions which contributed to the wide range and which could have been easily remedied if they had been recognized in advance.

This model provides a good example of how fault tree analysis could be used to save lives in the mining industry and is promising for application to other mine situations. It does not, however, deal with the initiation or propagation of mine fire; and as such, it has no direct applicability for the present project.

The second model covered here was developed by H.E. Nelson, (1981, unpublished), for the U.S. Bureau of Mines. This model is an event tree used to evaluate the fire safety performance of a coal mine. The model was developed in two parts: the first detailing the requirements for the prevention of fire initiation, and the second, the control of the impact of such fires that do occur. The model was intended as a preliminary approach and not to be applicable to any specific mine situation.

The Nelson model details the processes of: 1) the transfer of heat energy to a combustible material, 2) the kindling and ignition of that material, 3) the successful extinguishing or containment of a fire, and 4) the limitation of the damaging consequences of a fire. It does not consider specific combustible materials or their presence in specific areas of the mine, nor does it detail specific sources of ignition and their occurrence in specific mine areas. Also, the model incorporates some primary events that would be very difficult to obtain probability data for in a specific mine application.

Thus, Nelson event tree is an example of the non-specific model type described above. While it provides interesting background information on the mechanics of fire initiation, it would be impossible to apply it directly to the Cape Breton situation or to use it as the basis for a practical model to suit the project requirements.

Paraphrasing Nelson's model, fire initiation requires the following:

- Potential fuel (a combustible material) is present in the area.
- Potential fuel is exposed to heat sources (i.e. within influence of sources of heat energy and not insulated from them).
- Concentration of fuel (ratio to oxydizer) is high enough, but not too high, for combustion (i.e. there is enough fuel and there is enough oxygen, given the amount of fuel).
- Surface temperature of fuel is above a critical temperature required to volatilize sufficiently to be ignitable. (This temperature may be, depending on the fuel, at or below the ambient temperature or it may be above, in which case incident energy must be available, must reach the fuel and must be able to raise the surface temperature of the fuel, which depends on the amount of energy reaching the fuel and the characteristics of the fuel).
- Presence of an igniter (source of sufficient energy to raise temperature of ignitable fuel to ignition point). This may be an external heat source ("pilot" igniter) or energy source which can raise the temperature of the fuel or (in the case of spontaneous combustion, heating internally induced by oxidation reactions).
- Failure of systems designed to prevent ignition in case of any or all of the above conditions being true (flame arrestors, sprinklers, auto-shutoff devices, etc).

Note that there are two temperature limits, one to cause the fuel to "volatilize" and another one, presumably higher, to cause ignition of a sufficiently volatilized fuel. These both refer to the surface temperature of the fuel and in the event that they are above the ambient temperature, they both involve an external energy source which must both be capable or "influencing" the fuel (that is, in proximity of the fuel and not insulated from it) and also have a sufficiently high level of output to increase the surface temperature of the fuel given its resistence to the particular form of energy (reflectivity) and to increases in temperature (thermal inertia). An alternative to the external energy source is the case of spontaneous combustion where internal processes generate sufficient heat to raise the temperature of the fuel to the ignition point.

In Nelson's model, fire initiation will occur when the following events happen:

- A level of oxygen sufficient for combustion.

- Combustible material present is in ignitable condition, given the level of oxygen. This precludes methane below ignitable concentrations, etc.

- Source(s) of heat sufficient for ignition of combustible material is (are) present. This requires that something (or things) in the area is (are) producing enough heat energy, which, if applied to the combustible material could raise its temperature high enough to ignite; this implies both volatilization and ignition temperatures.

- Sufficient heat energy is transfered to the combustible material to raise it to ignition temperature as above (given that sufficient energy is available). This requires that the combustible material must be close enough to the heat source(s) to be affected by radiant heat and not insulated from it (them), or that the heat be transferred by conduction or convection. Generally, the conductor will be air which is a relatively poor heat conductor and thus the fuel and energy source must still be relatively close. Another possibility is a spark or flame will carry the heat across space.

- The temperature of the combustible material is raised to its ignition point, given that sufficient heat energy has been transferred to it. This requires that the transferred energy is not reflected or dissipated and that nothing maintains that material below its ignition temperature.

Theoretically, almost all chemical and mechanical processes generate some energy which is released into the environment and would, if transferred over a long enough period of time to a combustible material with no dissipation, raise it to its ignition point. In practical terms, however, an unusually high level of energy production is generally required to raise a material's temperature to the ignition point. This energy must be produced, be transferred to the combustible material, and be absorbed by the material so that its temperature increases. The amount of energy required depends not only on the ignition point of the combustible material but on the heat absorption characteristics of the material, the ambient temperature and the ability of the environment to dissipate heat energy as well.

In Nelson's model, there are several instances where events may interact, particularly where the action of fire prevention systems is relevant. For instance, the high temperature required to initiate combustion in certain areas may trip off alarm systems which automatically turn on sprinklers or foam spreaders and shut off power in the area thus affecting a change in the ambient temperature, level of heat production, and/or level of oxygen. This will, hopefully, avert the initiation of fire, or extinguish any fire which had begun.

Another example is the use of methane detectors which sound an evacuation alarm and automatically shut off power to all mining equipment when the methane/air mixture reaches an a concentration of 1.25%. This level is a safety cut-off level, above which there is a chance of ignition. This interaction affects the likelihood of a heat source causing the ignition of methane because, assuming the system functions adequately well, the number of possible heat sources is greatly reduced whenever methane is in an ignitable condition (with its concentration above 1.25%).

A final example of this kind of interaction is the connection between the requirement for a sufficient oxygen level in the air in order to have any kind of combustion and the concentration of methane gas necessary for an explosion.

2.2 Fault Tree Analysis

Description of Mathematical Methodology

The components of a fault tree model are events, which in conjunction with other events, lead to the undesired target or top event. Some of these events will be inputs to the model and not derived from other events lower in the tree. These types of events are referred to as "primary events" (other terms in use are "terminal" or "basic" events).

Other events will be intermediate, which are defined in the model to be the result of some combination of events "lower" in the tree and which are contributory for events "higher" up are termed intermediate.

One event in the tree is the "top" event, the undesirable situation or condition that is the object of study, and to which all other events contribute to the probability of its occurrence. All events are designated as being true or false. An event is true when it occurs or when the condition which it infers exists; otherwise, the event is false. A so-called "quantitative" model further assigns a value to each event for its' probability of being true.

The relationships between adjacent events in a fault tree model are expressed using the basic logical operators: AND, OR and NOT. The use of the AND operator requires that two or more input events are all true before the result event can be true. The OR operator allows the result event to be true if either of the two or more input events are true. The NOT operator defines the result event as being true only when the single input event is false. Thus, each event in the fault tree is defined as being the logical result of some number of input events.

The actual connection from input events to the result event event is called a "gate" and there are AND, OR and NOT types of gates. The result event is referred to as the output. Thus, an AND gate defines its output event as what happens when all of the related input events are true. In contrast, an OR gate defines its output as being true when any of the related inputs are true. A NOT gate can have only one input and defines its output event as occurring only when its input is false.

The analogy of the tree is best understood by visualizing an upside down tree (without roots). The top event is then the "trunk" of the tree and is related by a logical gate to a number of "branch" events. These events are each related in turn to a set of "similar branch" events and so on. The primary events which are not broken down any further are the "leaves" of the tree.

Thus, the tree is a diagramatic representation of the logical pattern of events which can lead to the target or top event. All event paths can be traced from the top event down through the intermediate event branches to some number of primary events. The exact nature of the combinations of the events required to produce the top event is represented by the gates.

When a given event has a number of alternative possibilities, it is related to the events for those possibilities by an OR gate. When an event has a number of requirements which must be met in order for that event to be true, it is related by a AND gate to the events for those requirements. Thus, for an OR gate, the inputs are not causes of the output event but, rather, are more specifically defined instances of it.

In contrast, the AND gate specifies that the input events are causally related to the output event (that is, the combination of the input events collectively represent the cause of the output gate).

NOT gates are seldom used in fault tree modelling. Many authors state that NOT gates are never needed if events are all stated in the correct sense in relation to the top event (that is, as a fault). This is mainly a matter of convenience and other authors do use NOT gates. We have not used NOT gates explicitly, however, in at least one case, a primary event in one branch of the tree is the logical negation of an event in another branch.

In some cases other types of gates may be used. Examples are: the "Exclusive OR" gate, where the output is true if one and only one of the inputs are true; the "Inhibit" gate, where the output is related to an input event if and only if a second "condition" event is true; the "priority AND" where the output event is true only when a given set of input events occur in a specific order. All these special gates can be expressed in terms of the simple AND, OR and NOT operations (this is a provable result from Boolean algebra, see below) and are used merely as space-saving shortcuts. Again, we have not explicitly used any of these gates.

Underlying the use of logical operators in fault tree analysis is the mathematics of Boolean algebra. This is the study of expressions involving logical operations such as AND and OR and how they can be combined and manipulated (much as regular algebra does for expressions using the ordinary operations of addition and multiplication). For instance, it can be shown that occurrence of one of X or Y and of one of X or Z is equivalent to the occurrence of X or both Y and Z where X, Y and Z are distinct events. This is the Distributive Law:

(X OR Y) AND (X OR Z) = X OR (Y AND Z)

The use of these rules allow a tree to be simplified or re-structured in any number of different looking but logically-equivalent forms. This ability to re-structure the model, or equivalently, to represent the model as a logical expression which can be mathematically manipulated, is particularly important in analysis of the fault tree model. Most qualitative and quantitative analysis methods require that the model be in a specific form. Section 3.3 of this report contains more detail on these topics.

Approach to Fault Tree Modelling of a Longwall Coal Mine

The first step in any modelling effort is to define and characterize the object of the study in systematic terms which can be applied to the model. The process or processes being studied must be understood as a system with components and functional relationships or interactions among those components. The functional relationships must be expressed in a way suitable to the modelling methods being used. Typically, this might involve a schematic diagram and/or a set of equations expressing the components and their interactions.

With a mechanical system, a schematic representation is usually straightforward with the system components being the parts of the machine and the laws of physics and mechanics providing formulae for the functional relationships. With a demographic model, based on population dynamics, the usual approach is to define various population groups or species, further divide them according to spatial and temporal factors as appropriate, and use these as system components with theoretical or statistically-derived functions giving the flows among them.

The general process of fire in a coal mine does not readily fit into the mechanistic or population-based system models. The tremendous variety of ways a fire can occur in a mine make it an extremely complex system. As such, it has been a difficult subject for modelling efforts. Fire is a complex set of chemical and mechanical processes that interface with possible human activities. For instance operator error, carelessness, vandalism, etc. which might cause fires and also efforts to prevent and extinguish fires. These human factors are particularly difficult to define and predict.

The difficulty of identifying and mathematically characterizing all of the significant controlling factors involved in each process makes many strictly mathematical modelling methods unsuitable for systems such as this.

A coal mine system entails a large number of processes that are event sequences and essentially random in nature. The potential for fire involves the interaction of mine structure, operation and environmental conditions. The fault tree modelling method is particularly appropriate here because it is basically qualitative, concentrating on the chain of events leading to a target event, in this case a mine fire. It enumerates all possible process paths that lead to the target using logical connectives to functionally relate them.

As with any modelling effort, three major steps are involved in constructing the model:

- Define the limits of the system (scoping); decide exactly on the spatial, temporal and functional elements of the model and their limits and resolution.
- Designate components as the functionally-distinct parts in the system and characterize them over the spatial and temporal scales.
- Define the functional relationships between components and express them as appropriate for the modelling method.

We will limit our consideration to the operation of a longwall mining system. It should not be necessary to be any more narrowly specific. Likewise, to be more general, we would risk losing sufficient detail in the model to make it applicable in a specific case.

The basic process being modelled is one of fire ignition. In the simplest qualitative terms, what is required to start a fire is the presence of combustible materials, an energy source, such as a spark, an open flame, or friction and an adequate level of oxygen.

An apparent exception is spontaneous combustion where no external triggering source is needed. In this case, the combination of combustible materials and environmental conditions can allow a fire to start.

The propagation of a fire, once started, is a functionally distinct process, contingent on the continuing presence of combustible material, which may not necessarily be the same material as initially ignited, and the continuation of heat and oxygen to sustain the fire.

In developing the approach for this model, we first considered that the fire hazard associated with wood usage in the mine could be characterized as: 1) those hazards which could result in a mine fire initiating in wood, and 2) those which involved the propagation of an ongoing mine fire to wood.

In the first case, a combustible wooden object in the mine is ignited by some heat source not associated with an uncontrolled fire. For example, a motor overheats and ignites its wooden support or sparks from a shearing operation or malfunctioning elecrical equipment touch and ignite a nearby pile of stored wood.

In the second case, wood is ignited by heat from an unintentional fire which has started in some other combustible material besides wood. For example, a methane explosion or gob fire ignites a wooden support, thus, causing the propagation of a fire from one combustible material to another.

Clearly, the modelling of mine fires involving wood requires the study of all fires which may occur in the mine and their inclusion in the model as subtrees. Each possible source of heat for a fire ignition and each possible combustible material is thus explicitly dealt with.

Sources of heat could be sparks from the action of a coal cutter (shearer) on a pyritic nodule or stone intrusion in the coal face, flame from a misjudged blasting operation (shot), friction from a conveyor belt roller because of a worn-out bearing or because the belt was caught, or excess heat, sparks or flames from various pieces of electrical, diesel, or mechanical equipment that might be present in the area considered. Contraband smoking was also considered as a heat source.

Combustible materials to be considered included wood, stored explosives, lubricating oils and fuels, plastics, electrical insulation, conveyor belt material, cloth, paper, and so on. Also important was coal and the associated methane gas which can be present at hazardous levels at the face or in any return air flow of the mine.

A fire could occur if there was combustible material a heat source and oxygen present in the same mine area at the same time. Thus, a specific fire hazard defined as the logical AND of three events: the joint presence of oxygen, combustible material and a source of ignition in a specific area. This would be repeated for every combination of heat source and combustible material possible. Spontaneous combustion was considered as an extra hazard.

Two separate cases for the transfer of heat energy from the source to the combustible material were defined. First, the issuance of a spark or flame which jumps or falls into the combustible material, igniting it. Secondly, the production of heat energy, without a spark or flame, which is transferred to the combustible material by radiation, conduction or convection in a sufficient amount to raise the material to its ignition point. Thus sources of heat for ignition were grouped by those which are spark or flame producing and those which generate heat alone.

The various combustible materials, possible sources of ignition, and environmental conditions vary widely in different areas of the mine and depending on what activities are taking place. Certain specific areas and operations have unique hazards associated with them while other hazards exist at almost all areas in the mine at all times.

In order to produce a model that could be practically applied to an entire mine system, it is necessary to consider each area of the mine and to incorporate differences in the type and probability of fire hazards in each area. A breakdown such as that used by Haslett (1984) was considered a good basis for conceptualization of the mine system.

For instance, the possibility that a mining machine will strike stone and cause a spark that will ignite methane need only be considered at the face and only when the machine is operating. In contrast, the possibility that an open flame or a spark from electrical equipment may ignite a pocket of unventilated gas will always be a factor.

Thus, as spatial divisions, we will have those areas of the operating mine defined by operational status. Thus, all working faces will be a single area. Similarly, the entry tunnels, return tunnels, development tunnels and abandoned areas will constitute separate compartments.

The various activities carried out in each area will define temporal division. For instance, a working face might have four states: an active state where the shearer and face conveyor are operating, a state where mining is stopped and equipment is being moved and reset, a state for blasting activities, and a state with no activity. Within each of these areas, each possible combination of sources of ignition and combustible materials must be considered. Such combinations are termed "hazards".

Many of these combinations will occur for more than one and perhaps all areas and activities in the mine. In each area and for each type of activity, there can be differences in the factors controlling the possibility of a hazard. Therefore, these otherwise common instances will be treated as distinct events.

Thus, there are a number of fairly repetitive alternatives. To reduce the size of the model and avoid too much duplication, some items were grouped together where fire hazard factors were judged to be constant and/or where probabilities for the group behaviour would be more obtainable than for its parts. For example, all cutting or drilling operations in coal or rock were combined for a given area. Similar groups were defined for electrical equipment, combustion equipment (for example, diesel engines), and mechanical equipment (with moving parts).

Such groupings led to three types of combustible materials: methane and suspended coal dust were combined because they are both airborne, therefore behave somewhat similarly, and because their flammability is inter-related. Loose coal (such as pieces on conveyor belts) and accumulations of coal dust on surfaces in the mine formed another group.

Everything else, including wood, was in the category of imported flammable materials, a term used by Dames and Moore (1979). Although there is substantial variation within this group with respect to flammability and distribution within the mine, there is the significant difference that control can be exerted over the type and amounts of material brought into the mine, and on where it goes.

To differentiate between different specific imported flammable materials, this branch would be replicated for each such material. For example, in an application for assessing the risk of wood fires, wood materials would be placed in a separate branch from other imported flammable materials in every area where it occurs. This branch and the others would, however, probably be identical with respect to structure, (i.e. gates, events and logic), differing only in primary event probabilities.

Finally, some mine areas were combined. All permanently-developed mine areas, all developing areas, all abandoned areas, were each represented by a single branch. Splitting these branches into finer divisions might be undertaken in a quantitative application. Such splitting of branches was not deemed appropriate at this stage because such split branches would probably differ only by probabilities and because the model is already fairly massive compared to others (Nelson 1981, Denny 1978).

A further reduction in the size of the model was accomplished by maximizing the extent to which events are placed as highly as possible in the tree rather than having them occur several times in lower branches. For instance, the presence of oxygen is mentioned once for each area before the branches for combustible materials are developed. Likewise, the presence of a given type of combustible material in an area was mentioned once for each such material type and area before the sources of ignition for that material are considered.

It was not possible, however, to factor all common events out of the tree. The events for the production of heat by the various heat sources in each area are repeated in the branches for each combustible material in each area. It is explained elsewhere how a tree can be restructured according to the rules of Boolean algebra.

In summary, the model presented here is quite large in terms of the number of events (1,225) and pathways (857), but it is fairly simple and straightforward in its structure and concept. There is a great deal of duplication in the logic sub-branches at each level. It is the probabilities of the primary events in each branch which are potentially different and which must be considered individually when the model is applied and quantified.

The model for the initiation and/or propagation of a fire in wood has not been completely detailed here but could be accomplished by re-structuring of the model so that the initiation of fire in wood is the top event.

Our design objectives in the devleopment of this model have been as follows:

1. To produce a qualitative fault tree model which conforms to the rules of fault tree construction and to which any standard method of analysis can be applied. To this end, the use of special purpose logic operators and non-probabilistic events have been avoided.

2. To be comprehensive in including all possibilities that could lead to the given top event, yet to be detailed enough that all significant aspects of a given mine situation can be represented realistically.

3. To incorporate only primary events for which probabilities can reasonably be derived from data or be estimated by those familliar with the given mine operations and characteristics of the equipment used. This last step is particularly crucial in developing a model which has practical applications.

Usefulness and Limitations of Fault Tree Analysis

The main advantage of fault tree analysis is simplicity. In any modelling effort a compromise has to be made between including as much information as possible into the model to make it an accurate representation of reality and maintaining the model at a manageable size, by keeping the most useful and relevant information needed to understand the system and solve specific problems.

Various modelling methods generally differ in the types of information they deal with and the level of detail with which they attempt to represent reality. Some methods are best suited to detailed studies of specific functions for which there are numerous data. Other methods have been designed to look at large systems and their overall functioning, usually by sacrificing detail.

Fault tree analysis is a general systems modelling technique which by virtue of being qualitative, steady-state, single objective, and ignoring feedback, subsumes a great deal of detail to concentrate on the overall behaviour of a system with respect to the likelihood of a single event.

By making these compromises, Fault tree analysis, perhaps more than any other modelling technique, is able to represent large and complex systems in a comprehensive manner. For all of its shortcomings, it has proven capable of yielding very useful results in safety/risk applications that would be too complex for more detailed modelling methods.

Fault tree models are generally prone to the same problems as other types of models:

- Improper scoping of the system results in a model which does not match reality because the real system will be subject to influences not incorporated into the model.
- If the model design is not comprehensive in describing system behaviour, the real system will be capable of behaviour modes (in this case, event paths) which are not incorporated into the model.
- If the model design is not sufficiently detailed, then the real system will be capable of assuming states (in this case, events) which the model does not represent.
- In the case of a quantitative model, if the data used to calibrate and initialize the model are inaccurate, the results are likely to be unreliable.

In fault tree analysis, as with most other modelling techniques, the actual construction of the model is a subjective process, depending on the modeller's experience with the methods and intimate knowledge of the system. The spatial/temporal scoping, functional comprehensiveness and detail is entirely up to the modeller's judgment.

Having chosen the top event in a fault tree, the modeller uses knowledge of the system, deductive reasoning, common sense, intuition, literature, expert advice and whatever else might seem appropriate to determine the possible causes of the top event and then proceeds to develop the entire tree. Some level of subjectivity is inherent in almost all system models.

For a fault tree application to a specific system, the data requirements consist of assigning probability estimates (or possibly, ranges) for all the primary events of the tree. This is often referred to as quantifying the model, although, as noted below, this is somewhat of a misnomer.

For data collection, it is generally possible to generate all the required data by experimentation with the actual system and proper statistical treatment of the results. The modeller, however, may estimate many of the parameter values. In this case, success depends on the modeller having knowledge and experience with the system and a correct understanding of exactly what each primary event is meant to represent.

We have been careful in describing the primary events of our model, including the context of the event as passed down from higher levels in the tree. Each primary event is usually some possible occurrence given a set of conditions which we refer to as the context of the event. The probability of this event is the probability of the occurrence assuming that the specified conditions are true. Additionally each primary event is accompanied by a list of comments which attempt to describe all of the considerations involved in quantifying this event.

Limitations which are peculiar to fault tree analysis include the following:

A fault tree model is a completely qualitative representation of a system. The events of a fault tree have only two states, true or false. Although one can assign probability values to the events and evaluate the probability of the intermediate and top events, at no point does the model consider the magnitude of any system behaviour.

In some cases, events may refer to quantitative system behaviour, such as "temperature exceedes critical value". Temperature never becomes a system variable, and the model never directly deals with temperature. Only the event of it exceeding some set value is of interest. Thus, even with probabilities assigned, the model is purely qualitative and as such the term "quantifying" the model, referring to the assigning of probabilities, is somewhat misleading.

A simple fault tree model is a steady state representation in that time is not considered as a system variable. As with quantitative behaviour, in which time can be considered to be varying, some events may incorporate time-related conditions, but the model does not directly use this information. Some recent developments have been made in the field to develop a special form of the analysis which does incorporate time which are described briefly in Section 3.3 (Future Development of the Fault Tree Model).

The lack of quantitative information (in particular, time) in the model means that cumulative effects are not handled well. To select an example from our model, the possibility of electrical equipment overheating and igniting a combustible material is specifically dealt with in the model. The case where the combined heat from electrical and mechanical equipment caused a fire, however, is not covered; nor is a case where a spark from some source ignites a material already raised close to the ignition point by heat from another source; nor when two sparks together ignite a material. In most cases, such combination events are rare. They could be modelled either by resorting to non-standard, non-probabilistic mechanisms such as the "function" gates used by Nelson or by adding an event path for each combination to the model.

A fault tree model is restricted to a single objective function, that being the top event and its probability. Thus, one cannot use the same model to track several variables of interest as in many other methods. Each condition of interest must be formulated as a top event and developed as a separate tree for that event. For instance, the cases of fire initiation of wood and fire initiation of any combustible material require the development of two separate trees, although mostly the same set of primary events would be used in both.

Fault tree models do not have feedback mechanisms. The event logic process is required to move up the tree towards the top event. In no case is a high level event allowed to determine one of its predecessors as a feedback loop might imply. In fact, when developing an event one assumes that the event is not already true. Thus, using "initiation of fire anywhere in the mine" as a top event implies the condition "given that no fire exists anywhere in the mine" on all events in the model.

The lack of feedback limits the way in which propagation can be represented. It is possible to model a "one-stage" propagation event by simply defining an event such as "a fire in area 2 is ignited by a fire in area 1". Multi-stage propagations are possible but each propagation path would have to be specifically modelled as an event path. To model all such paths in a typical mine would be a monumental task.

When complex systems of interacting variables have large amounts of feedback, the effects resulting from the feedback pathways may dominate the effect pathways directly through the system variables. These feedback effects are termed "indirect" effects. The lack of feedback in fault tree analysis also means that such indirect effects are not recognized. Again, research in this field is continuing to develop these techniques.

3.0 RESULTS AND DISCUSSIONS

3.1 Description of Longwall Coal Mine

Longwall coal mine operations at CBDC represent complex mining systems. The list below outlines the components of the mining systems that were considered in developing the fault tree model. Since a model is a simplification, or an abstraction of reality, not every physical component of the real system is included in the model. The key to successful modelling is not to be comprehensive in a physical sense but rather to capture the essence of the system structure and function dynamics that affect the variable(s) of interest, for example, the top event as simply as possible.

The functional areas of a longwall coal mine considered by this model and described below (the numbers refer to the corresponding branch numbers in the tree) are:

1. the working panel, consisting of:
    - 1.1 the face area,
    - 1.2 the intake gate road,
    - 1.3 the return gate road,
    - 1.4 the gob
2. the main tunnels and permanent installations
3. the developing areas
4. the abandoned areas.

TABLE 3.1

OBSERVATIONS/ASSUMPTIONS MADE REGARDING THE MINING METHODS USED AT CBCD FOR DEVELOPMENT OF THE FAULT TREE MODEL

Functional Area	Sub-Area	Observation/Assumption
Working Panel	Face	. limited wood on a normal operating basis . major combustible matter is: - methane liberated from the face - coal dust liberated while cutting - methane and coal dust mixture . water spray on shear "picks": - quenches sparks - allays coal dust . methane monitors at the shearer and at the "top" of the wall - automatic shutdown feature if methane concentration levels exceed 2.0%
Working Panel	Gateroads	. extensive use of wooden lagging and wooden gateside packs . intake gateroad developed by a Dosco Roadheader Cutting and Loading (DRCL) machine . exhaust gateroad developed by shearer extraction of the coal and a shotfired arch profile in the roof . rock-dusting is used as a fire prevention measure . extensive use of wood for: - ventilation doors - mechanical, electrical rooms - blocking behind corrugated steel lagging
Working Panel	Gob	. limited wood on an operating basis . spontaneous combustion potential which is a . function of: - flow rate of air leakage through gob - nature of the coal (prone to spontaneous combustion?) . methane gas concentrations may be high in the gob . methane drainage system (installed in the exhaust gateroad) 'bleeds' methane from the gob area

TABLE 3.1 (continued)

Functional Area	Sub-Area	Observation/Assumption
Main Roads		. extensive use of wood lagging and temporary support structures . varied function uses of mainroads, two assumed uses are: - intake: personnel transport and coal conveyance services - return services . fire hazard will vary based on function of tunnel . intersections are high fire hazard areas because: - wood used for intersection support - rail switches - rail car derailing - accumulation of flammable materials . there are permanent service installations in the mainroads: - belt operator stations - communications stations
Development Areas		. extensive use of wood lagging and temporary support structures . developed by two methods: - DRCL - shotfired . auxiliary ventilation by fan and ventilation duct is used
Abandoned Areas		. extensive volume of wood (lagging and packwalls) . some are permanently sealed and not ventilated . some are used in conjunction with the "Cundy" ventilation layout

Areas 2, 3, and 4 have several possible functional sub-areas for which separate branches should be developed if a quantitative model is constructed later. In such cases, each branch would have the same structure as the branch given for the area as a whole, only the probabilities attached to the primary events would differ.

In the development of the fault tree model, no distinction was made between the advance longwall system with in-line ripping of gateroads (Lingan Colliery) and the retreat longwall system with single use, single entry gateroads (Prince Colliery).

Observations and assumptions, regarding each of the four functional areas of the longwall coal mines at CBDC, were made during the model development process. These observations/assumptions are stated in Table 3.1.

3.2 Description of the Fault Tree Model for a Cape Breton Coal Mine

A diagram of the fault tree model is given in Figure 1 which follows Section 3. The first page gives the key to the symbols and illustrates how the events are numbered. On the second page, is the overview of the model structure illustrating the four basic areas and four subareas and how they are connected to the top event.

The Appendix (Section 5) details the Fault Tree model with full explanations of the events and commentary on what factors and considerations affect the probability that might be assigned to this event in a quantitative model.

In this model the top event is "The initiation of fire in the mine". Note that by definition this presupposes that there is no fire already burning in any part of the mine. It is important to keep this in mind throughout the model. All events in the tree are in the context of the top event and subject to the any restrictions imposed on, or implicit in, the definition of that event.

The same concept applies throughout the model. Conditions which apply to an event apply to all events in the tree below. In other words all events are in the context of the events above them in the tree. In the Appendix, these conditions are stated explicitly as a series of phrases starting with "given that", following the description on the event. These conditions are carried through the tree to subordinate events so long as they are relevant. In Figure 1, conditions are not stated and are to be assumed from the position of the event in the tree.

As in most modelling efforts, the system to be studied is first defined exactly and bounded (this is referred to as scoping the model). That is, spatial and temporal boundaries, as appropriate, are decided upon. As well, the limits of resolution, spatial and temporal, are set. These so-defined spatial/temporal units or compartments are then considered as separate sub-systems. This process is referred to as compartmentalizing the model.

Subsequent to compartmentalization, Variables for the measures of interest are defined for each component and the functional relationships between them are characterized. Certain of these relationships may be deemed objective functions in that their value is a measure of interest for the system as a whole. Quantities which control those relationships without being changed themselves are referred to as parameters.

Spatially, the model will focus on all underground areas of the mine and will consider the hazards of fire in the functionally distinct area that might exist in the mine at any given point in time. Time is not a factor in this model.

For these purposes, an active working face is considered as a distinct functional area. Within this area, there may be localized conditions of greater or less hazard, but these were not considered to be significant factors, at least, for a qualitative (non-probabalistic) model. Likewise, it is not anticipated that there would be significant differences of a qualitative nature between different faces in the same mine. As such, all working faces in the mine are considered as one spatial compartment of the model.

Other spatial compartments are: all intake gate (coal level) roads to active faces, all return (material level) roads to active faces, all developing areas of the mine, all abandoned areas of the mine, and various types of main mine tunnels (slopes and deeps) where each combination of air (intake or return) and usage (men/materials or coal) would constitute a separate type.

The variables involved in the ignition process are the events representing in each compartment the presence of a combustible material, the presence of oxygen in contact with that combustible material, the temperature of the combustible material being raised to its ignition point, and the initiation of fire. The first three will be inputs to the model while the last is evaluated within the model.

Parameters of the system are such things as the ambient temperature, the human traffic levels, the proneness of the coal in the mine to spontaneous combution, and so on, which appear in conditioning events.

The functional relationships among these variables/events and with any system parameters are given as logical relationships defined by the structure of the tree. An important relationship among the variables is that the co-occurance of the input events listed above causes the output event of fire initiation.

This in principle is referred to as the "fire triangle". Fire is a complex chemical and physical process which belies the simplicity of this concept. For the purposes of this qualitative fault tree model, however, it will prove useful. This is implemented by making the event of fire initiation the result of an AND operation between the events for the three requirements. Every combination of these three events represents a possible way a fire could be initiated and will be termed a hazard.

The objective function is the top event which as explained above is the initiation of fire anywhere in the mine. This is defined to be the initiation of a fire in any compartment. Compartmentalization is thus implemented in the model by using one or more levels of OR gates to describe the systematic top event as being a similar specific event in any one of the given compartments.

The top event is connected by an OR to branches representing an event in each of the areas. Each of these branches, is connected, also by an OR, to an event for each of the combustible materials in that area. To these, the hazards for each area and combustible material are also connected by OR gates.

Examining the hazard relationship in more detail, the temperature required for ignition varies greatly depending on the combustible material in question and in many cases, the state of that material (ie. solid, liquid or gas). In most cases, it is assumed that this temperature is achieved because of some heat source in contact with or close to the combustible material. This is referred to as an ignition source and may be a heat-producing object which transfers heat to the combustible material either by radiation, conduction, or convection. The ignition source may also be a flame applied directly to the combustible material or a spark which lands on the material.

An exception to the requirement for an ignition source is the process of spontaneous combustion. In this case a combustible material in contact with oxygen, undergoes an oxidation reaction which is too slow to produce a flame. The speed of this reaction is controlled by the ambient temperature of the material. Depending on the speed of the reaction, however, heat is produced which, if not dissipated, will raise the temperature of the reacting material and increase the speed of the reaction. This process of self-heating, will, if continued for long enough, raise the temperature of the material to its ignition point whereupon a spontaneous combustion fire will occur.

Certain materials, because of their chemical properties, are prone to spontaneous combustion. Coal, in general, is prone although some types are more prone than other. Normally the wood used in mine structures is not prone to spontaneous combustion. Decomposing wood which may be present in abandoned mine areas or in the "gob" area of a longwall panel, however, may be involved in spontaneous combustion.

The special case of spontaneous combustion is handled by a special alternative hazard in each area. This hazard is defined as the co-occurance of material prone to spontaneous combustion, ambient temperatures above a critical value, and air-flow in contact with the material between limits which provide sufficient oxygen but do not dissipate the heat generated by the oxidation reactions.

In most cases the requirement for oxygen in contact with any combustible material in the area will be equivalent to the condition that there is a sufficient level of oxygen in the air at the area. This condition will be the same for all combustible materials and heat sources in the area. Therefore the event of fire initiation in the area will be the result of an AND gate connecting the event that there is a sufficient oxygen level in the area to support combustion and the event that (given the level of oxygen in the area) some combustible material is raised to ignition temperature.

The event that there is a sufficient oxygen level in the area to support combustion is a primary event which is not developed further in this model. In probabilistic terms, the likelihood of there being a high enough oxygen level in any non-abandoned mine area will be high. The level of oxygen will not likely affect the possibility of a combustible material being raised to the ignition point but the condition is included in the definition of the event for the sake of formality and completeness. It should be noted that a continuous supply of oxygen is a requirement for fire propagation but that is a separate issue from fire initiation and has not been considered.

For the event that some combustible material in the area is raised to its ignition temperature, there are many alternative combinations of combustible materials and heat sources. It was decided to group these by the combustible materials in the area. Thus, the event that some combustible material is raised to its ignition temperature is the result of an AND gate joining the presence of the material and the event that the material (given that it is present in the area) is raised to its ignition point.

The presence of the specific type of combustible material in the area is a primary event which is not developed further in this model. When the model is quantified, a probability for this event must be worked out or the factors involved in the possibility of that material being present could be considered and the event developed further in the model.

The event that a specific combustible material in the area is raised to its ignition temperature has many alternatives depending on the various possible heat sources in that area which could ignite the given material. This event is then joined by an OR gate to events for each of these alternatives. These alternative events will include all ignition hazards in the area for that combustible material such as incendive sparking, improper blasting operations, electrical arching, electrical overheating, overheating because of mechanical friction, improper use of or malfunction of internal combustion equipment, and contraband use of flame where appropriate.

In each case, an event will be defined as the situation causing a given heat source occuring and raising some quantity of the given combustible material in the area (given that it is present in the area) to its ignition temperature. Implied in this definition is the requirements that the heat source occurs in contact with the combustible material or near enough to it that sufficient heat is transmitted to appropriately raise its temperature. Heat sources in adjacent areas could affect combustible material in the area of concern. These events are primary events and not further developed in this model. Again, in a quantitative model these events could either be assigned probability values directly, or their underlying mechanics developed further.

This sequence of gates from top event to the primary events, describes in general how each possible hazard of fire in the mine is modelled. Each such hazard has a separate event path in the model which branches down from the top event as explained above. In most cases, all the branches follow the same pattern.

To compare the relative size of previous models with this model consider the following information:

The model developed by Denney, et al. (1978) for miner fatality in the event of a mine fire had 1 top event (as do all fault tree models), 32 intermediate events and 52 primary events for a total of 85. There were thus 32 gates (one for the top event and each of the intermediate events) and the maximum depth (number of gates between the top event and a primary event) was 6. The top two gates of the model were presented by the authors as an event tree and recast (by us) for the purposes of this enumeration.

In Nelson's event tree model for acceptable fire safety performance (prevention of fires or control of those fires which do occur), there are 63 logic gates joining 1 top, 62 intermediate, and 80 primary events (of which probably 73 are unique), for a total of 143 events. The maximum depth of any branch was 10 gates. It should be noted that this model incorporated several OR gates which were termed "multivariate" where the probability of the output is a special function of the probability of the inputs. They have been counted as ordinary gates. Several of the primary events were developed as functional branches where the probability of the primary event was described as a function of several (non-probabilistic) parameters which are listed as events. These branches have not been counted.

This basic fire initiation model as displayed, has 1,225 events of which 367 are intermediate events, 857 are primary events and 1 is the top event. Of the primary events 520 are unique (the rest being duplicates in cases where a primary event inputs into more than one gate). There are 368 gates (one for the top event and one for each intermediate event). The maximum depth is 12. There is a great deal of structural redundancy in the model. Of the 7 main branches which are directly related to the top event, 6 are structurally identical.

These measures are somewhat subjective since in a practical application of a model to a particular system there might be occasion to split some branches to allow for each of several possibilities which were considered as one in the model as presented. Such split branches would probably have identical structures but with different probabilities for the primary events. Some primary events in different branches which were considered as being closely related might, given the application and specificity of the available data, be taken as identical.

Finally, the number of gates and intermediate events depend on the form in which the model is presented. By the rules of logic (boolean algebra) a model can be expressed in many structurally-different but logically-equivalent forms which will differ in the number of gates and intermediate events used.

Practical Limitations of this Model

Many of the shortcomings and limitations of this model were mentioned in the previous section. The model has been designed to be comprehensive but as it stands it may be over-generalized in some aspects such as the grouping of all main mine areas and permanent underground installations in one branch, the grouping of all imported flammable materials into one branch, or the grouping of all equipment of a given type (electrical, combustion, or mechanical) into a single category. We feel the model, however, is easily expandable in this respect where a given application and available data warrant it.

There were nine points which were raised in the initial statement of work to be included in the model. Of these, points (iii), possible ignition sources/mechanisms, (v), open and concealed fires, and (viii), methane and coal dust accummulations have been most directly examined in the current qualitative model. Detailed consideration of points (i), personnel traffic levels, (ii), machinery, plant, and equipment in various mine areas, and (iv), construction materials and methods for supports, etc., will not be relevant until the model is quantified for a particular mine.

Point (ix), rates of propagation/development has been considered in a limited sense as explained above. Fault tree methods can be used to estimate the likelihood of a specific propagation event (such as from one material to another or from one area to another). To estimate the likelihood of any propagation would require the enumeration of all possible event paths for such propagation and results in a very large model. Fault tree methods can not be used directly to estimate reaction rates.

Points (vii), detection, and (vi), evacuation and control, have not been addressed at this point but could be implemented in future work on this model. Based on the work of Denney, et al, and Nelson (unpublished) these points would necessitate an expanded model double and perhaps quadruple the size of the present one.

The application of this model will likely be most seriously limited by the availability of data, this being the case with almost all models of any type. Despite our efforts to make the primary events relevant to mining operations, the educated guesses of knowledgeable individuals as to the probability level of a given event may have to suffice in some cases.

Theoretically, the most serious problems could arise with cumulative effects and heat build up from multiple sources. As explained in the previous section, such cases are not covered in the model, an example being where heat energy from two sources (such as an electric motor which is overheating because of both electrical overloading and mechanical friction) ignites a combustible material which would not have been ignited by the heat from either source alone.

Another theoretical difficulty is the lack of time sensitivity in the model. One case in which this is a particular problem is in the event dealing with the evacuation of the mine when high methane levels are detected. In the model when such methane levels are detected, the panel is instantly evacuated. In reality, of course this is impossible as it takes some time for the evacuation process and this may be a particularly high hazard situation. The build up of heat in a combustible material is also a time dependent process. Time dependent relationships like these or the servicing of a critical piece of machinery to prevent hazardous situations can be included in a more quantitative form of the model.

3.3 Analysis of the Model

The model is presented in this report in a qualitative form which outlines the causal mechanisms leading to the top event. Most of the useful results of Fault Tree Analysis come through analysis of the model in a quantitative form which entails supplying probability data for the primary events. There are a few results, however, which can be derived from the qualitative model alone. Most techniques, however, involve a quantitative analysis of the model.

Virtually all methods require that the tree be in minimal cut set form. This is a canonical form, that is, a model which is functionally equivalent to the original, which is derived from the original by the application of certain prescribed transformations, which conforms in its structure to certain rules, and for which all functionally equivalent models will produce canonical forms which are identical. Thus, the minimum cut set is a sort of lowest common denominator for fault tree models.

A fault tree in minimum cut set form has only one level of intermediate events. The top event is linked to all these intermediate events by a single OR gate. Each intermediate event is linked by an AND gate to the primary events, each of which may appear under various different AND's. A primary event which occurred in the original model as an input to a single gate may appear in the minimum cut set form as an input in several gates. It is possible that a primary event may be an input to the OR gate under the top event.

As constructed, a fault tree usually has the maximum depth (number of gates between the top and primary events) and the minimum repetition of primary events. In contrast, the minimum cut set form has the minimum depth (usually 2) and the maximum repetition of primary events.

The minimum cut set form is derived by redrawing the tree from the top down, removing intermediate events and gates, according to the following set of rules for each gate-event-gate combination.

If an event is an input of an AND gate and the output of an OR, the two gates and the event are replaced by an OR gate in place of the AND with the same number of inputs as the old OR gate. For each input a new intermediate event is created which is the output of a new AND gate. Each AND gate takes as its inputs one of the input events of the old OR gate and all of the remaining input events of the old AND gate. Note that each input of the AND, besides the one being removed, must be repeated as inputs to the new AND gates, one for each input of the OR gate. If the input event of a OR gate is the output of an AND, no action is taken. If the event is an input of an AND gate and the output of an AND gate, then the event and the AND gate below can be removed from the tree and the input of the removed gate can be made inputs to the AND gate above. Similarly, if an OR gate input event is the output of another OR gate, the input events of the gate below below are linked to the gate above. If identical events become inputs to the same gate, one of them can be dropped.

Thus the positions of the AND and OR gates in the tree are reversed if necessary with the OR's being moved above the AND's. Where gates of the same type are linked, they can be combined. The process is repeated down all branches of the tree until all AND gates have primary events as inputs and there are no AND gates between any OR gate and the top event. The tree is then in minimum cut set form.

This procedure can be perhaps more easily visualized by representing the tree by an equivalent Boolean expression and transforming it into other equivalent forms by applying the rules of Boolean algebra. Boolean algebra is a set of rules for working with expressions much like regular arithmetic algebra, with AND and OR as operators in place of multiplication and addition. The rules of Boolean algebra are in fact very much like those of regular algebra, with a few important differences. The NOT operator, incidentally, behaves much like an arithmetic negation, but again, with differences in the way it distributes over AND and OR operators.

For example, if we take a tree where the top event is joined by an AND to two events which are both outputs of OR gates. Each OR gate has two primary events as inputs, with the inputs to the first gate being labelled "A" and "B", and to the second as "C" and "D". This tree can be written as a Boolean expression TOP = (A OR B) AND (C OR D). It should also be noted that an OR gate with three inputs, labelled "A", "B" and "C", would be written as (A OR B OR C).

The rules of Boolean algebra required for reducing an expression to a canonical form equivalent to the minimum cut set are the following. The Rule of Associativity of OR and AND so that (A OR (B OR C)) = (A OR B OR C) and ((A AND B) AND C) = (A AND B AND C). The Rule of Distribution of AND over OR so that A AND (B OR C) = (A AND B) OR (A AND C). The Rule of Idempotency for OR and AND so that (A AND A) = A and (A OR A) = A. All these rules are the same as in regular algebra. Also like multiplication and addition, AND and OR are commutative so that the order of operands does not matter.

It can be seen that these rules are equivalent to the operations described above for reducing the tree.

One difference with regular algebra is that OR distributes over AND so that (A OR (B AND C)) = (A OR B) AND (A OR C). This rule, however, is not needed in reducing an expression. Another rule which is not found in regular algebra and which is useful in reducing expressions is the Rule of Absorption by which A OR (A AND B) = A. This implies that for a fault tree in minimum cut set form, if all the primary event inputs to an AND gate are also inputs to a second AND gate, that the second gate, its output intermediate event, and its inputs can be eliminated. This is reasonable because, if the primary event inputs to the first gate are all true, then this branch will trigger the top event and the extra events required for the other branch are redundant.

Applying the distributive rule (twice) to the given example shows that TOP = (A AND C) OR (A AND D) OR (B AND C) OR (B AND D). This expression is equivalent to a tree in minimum cut set form. The subexpressions with AND operators are the terms of the expression (the above has four terms). The events in any one term are collectively constitute a minimum cut set.

If all events in any one minimum cut set are true, then the top event will be true. Thus, the minimum cut sets are the sets of events which are required to trigger the top event. Each term or set can be thought of as a cause of the top event and the number of terms or sets is the number of different alternative causes of the top event.

The expression of the minimum cut sets as Boolean equations also facilitates the generation of probability equations for the tree. Two simple rules accomplish this:

$$\text{Prob}(A \text{ OR } B) = \text{Prob}(A) + \text{Prob}(B) - \text{Prob}(A \text{ AND } B)$$

$$\text{Prob}(A \text{ AND } B) = \text{Prob}(A) * \text{Prob}(B \text{ given } A)$$

Prob(A) refers to the "probability of event A" defined as the number of times event A occurs divided by the number of "trials" (operations where the event could occur) or as the amount of time a condition exists for a certain period of time divided by the length of that period. Theoretically, the true probability value can only be found if the number of trials or period of time is infinitely large. Generally, it is assumed that as the number of events becomes greater or the period of time longer, the probability ratio will approach or limit to its true value. An event which is rare or impossible will have a probability value which is low or zero. An event which is frequent or always true has a probability close to or equal to one.

The probability of the combined event (A OR B) is the sum of the two events minus the probability that they both occur, that is, the combined event (A AND B). It can often be assumed that the two events cannot happen together which is termed being mutually exclusive. If this is the case or if the likelihood of their co-occurrence is so low as to be negligible, then the formula above is simplified to

Prob(A OR B) = Prob(A) + Prob(B)

The probability of the combined event (A AND B) is given as the product of the probability of event A and the probability of event B given that event A has occurred or is true. The second probability is termed a conditional probability since it takes into consideration the extent to which the likelihood of one event is affected by the occurrence or existence of the other. Prob(B given A) is often written Prob(B|A) and it can be shown that Prob(A AND B) is also equal to Prob(B) * Prob(A|B). If the occurrences of the two events A and B are not affected by each other, then the two are said to be mutually interdependent. In this case, Prob(A|B) = Prob(A) and Prob(B|A) = Prob(B) and therefore, Prob(A AND B) = Prob(A) * Prob(B).

For all the above combined event probability formulae, the obvious extensions for combinations of more than two events can be made.

In fault tree analysis, primary events which are inputs to an OR gate quite often are mutually exclusive or nearly so. Similarly, primary events in an AND gate are usually assumed to be mutually interdependant or close to it. In fact, in constructing the model, events are often defined so that these conditions are explicitly stated.

Where these conditions are valid or are assumed to be so, the translation from Boolean equations to algebraic probability equations is accomplished by replacing OR's by plus signs, AND's by multiplication signs, and event designations by variables denoting the event probability values. It is, however, important that significant exceptions to the assumptions must be considered and appropriate adjustments to the formulae made. This will be a matter of the exact definition of the events and the behaviour of the system with respect to those events.

The matters discussed above are all illustrated in Table 3.2. Here we have taken as an example a subset of the coal mine fire initiation fault tree model. The branch for event 1.1 is used as an example. For simplicity events 1.1.2.2.1.2.1.2, 1.1.2.2.2.2, and 1.1.2.2.3.2 are considered primary events and have not developed them as in the model proper. Also we have omitted the periods in the event numbers. Thus, event 1.1.1.1 is listed as (1111) while the probability of that event is listed as P_{1111}.

Section (a) lists the minimum cut sets. There are five of them (in this version of the tree) and each is a set of primary events. The cooccurence of all the events in any one set will cause the top event to occur. The first set listed covers the possibility of spontaneous combustion of coal in the seam at a working coal face. The second set covers the ignition of methane gas and/or airborne coal dust at the face which is undetected or which does not cause the detection/alarm system to operate. The third set covers the ignition of methane and airborne coal dust which is detected and which causes the shut down of operations at the face and evacuation of the section. The fourth set covers the ignition of loose coal and accumulated coal dust at the face while the fifth set covers the ignition of imported flammable materials (which would include wood).

Section (b) gives the Boolean equation for the event 1.1 as defined by the minimum cut sets. This form clearly states the relationship of the primary events and minimum cut sets to the top event as stated in the paragraph above.

Finally, section (c) gives the equation for the probability of event 1.1 as derived from the Boolean equation in section (b). Note that mutual independence and exclusivity of events has been assumed and might not necessarily hold in reality.

TABLE 3.2 Examples of Branch 1.1 in Minimum Cut Set Form

a) Minimum Cut Sets for Branch 1.1

1. ((1111), (1112), (1113), (1114))
2. ((1121), (112211), (11221211), (11221212))
3. ((1121), (112211), (11221221), (11221222))
4. ((1121), (112221), (112222))
5. ((1121), (112231), (112232))

b) Boolean Equation for Branch 1.1 (in Min Cut Set Form)

(11) = ((1111) AND (1112) AND (1113) AND (1114)) OR
((1121) AND (112211) AND (11221211) AND (11221212)) OR
((1121) AND (112211) AND (11221221) AND (11221222)) OR
((1121) AND (112221) AND (112222)) OR
((1121) AND (112231) AND (112232))

c) Probability Equation for Branch 1.1 (in Min Cut Set Form)

$$\begin{aligned}
P_{11} = {} & (P_{1111} * P_{1112} * P_{1113} * P_{1114}) + \\
& (P_{1121} * P_{112211} * P_{11221211} * P_{11221212}) + \\
& (P_{1121} * P_{112211} * P_{11221221} * P_{11221222}) + \\
& (P_{1121} * P_{112221} * P_{112222}) + \\
& (P_{1121} * P_{112231} * P_{112232})
\end{aligned}$$

First, the minimal cut set can be used to search for common cause categories. In this analysis, the primary events are considered to see if some of them might be related by some common factor which could cause all the events in the category to be true. Each of the related events is replaced in the minimal cut set terms by a symbol for its common cause category and again the terms with the fewest causes are considered as potentially being the weak spots in the system. We did not pursue this type of analysis on this model as there were common causes apparent.

The minimum cut set also gives a good estimate as to the complexity of a given model. As explained before, just counting the events and/or gates in other forms of the tree does not give a meaningful result because the number of intermediate events and gates can be changed without actually altering the logic of the model. The minimum cut set form, being canonical, will be identical for all logically equivalent trees and as such represents a valid basis on which to compare models.

There are a few purely qualitative measures which can be applied to a fault tree in minimum cut set form without knowing anything about the relative likelihood of the primary events. All these methods essentially assume that all primary events have roughly equal probability and therefore the degree of hazard can be assessed simply by counting the number of primary events involved. This is termed qualitative importance.

For instance, referring to Table 3.2, section (a), we see that minimum cut sets 4 & 5 each have 3 primary events which can together cause the to event. Sets 1, 2 & 3 each require 4 events. The assumption of equal probabilities for all primary events implies that sets with more events have lower probabilities (since more conditions must be met for it to be true). In this case we have ignition of loose coal and imported flammable materials as being more hazardous than spontaneous combustion or ignition of methane.

While this may or may not be true, it must be noted that if we had used the minimum cut sets for the full tree, that the sets for all branches except spontaneous combustion would have been much longer simply because of the greater detail. This test would then suggest that spontaneous combustion of coal in the seam was the most serious hazard.

Similarly, the degree of hazard associated with any primary event might be measured by comparing the number of minimum cut sets it is in. In this case we see that the event for the presence of oxygen is in 4 out of 5 sets. Thus if we could remove the oxygen in the mine we would be significantly reducing the number of hazard pathways. True, perhaps, but not very practical. This test further suggests that methane is a greater hazard than loose coal or imported flammable materials simply because an extra branch was included to deal with interaction of the methane detection systems.

To see how actual probability values might be used in this model we examine Table 3.2, section (3). The probability of the top event, a fire in the face area of the mine, is the sum of the probabilities of five terms, each of which represents a distinct potential cause of a fire. The relative degree of hazards from each of these causes can be measured by comparing the values of these terms.

The first term of the probability equation gives the probability of a spontaneous combustion event. It is the product of probabilities for four primary events. P_{1111} will be zero (or very low) in mines were the coal is not prone to self heating and one (or very high) in mines where it is. If it is zero, its product with other variables in the term will be zero and the term will not contribute to the sum of probabilities for the top event. Thus, this event acts like a "switch" for this hazard.

Similarly, the last two event probabilities in this term are functions of the mine conditions (air flow through the seam) and both must be high if the value of whole term is to be significant. This leaves P_{1112}, the probability of a critical temperature being achieved. If the conditions implied by the other events are met and their probability values set to 1, then it can be seen that this term, the probability of spontaneous combustion in the seam, is equal to the probability of that temperature being achieved.

Looking at the next term, its first value in the product is the probability of adequate oxygen for combustion. Since this is unavoidable in a working mine, we can set this value as 1. The next value is the probabilty that an explosive methane/coal dust mixture will exist at the face. One important point to consider here is that this event alone is not independent of the preceding requirement for oxygen since a high enough methane concentration will displace the oxygen in the air. Thus, this probability is conditional on the requirement for oxygen and it effectively measures the proportion of time that methane concentrations are within certain limits. One would hope this value would be quite low although in mines with high methane concentrations, it will be higher.

Continuing with $P_{11221211}$, the probabilty of mining operations continuing in high methane, we can see that this event must be defined conditionally, as the probability of mining continuing given that there is an explosive methane mixture present. Again, because of the use of automatic and manual methane testing and observed precautions, we can set this value quite low. The final value in this term is $P_{11221212}$, the probability of a suitable heat source, again, given the presence of the methane. This time the condition should not make much difference since the mining operation unavoidably generates heat which is sufficient to ignite an explosive methane mixture whether it is present or not. This value, then, should be relatively high.

Thus, for the second term we have the product of four probability values. One (P_{1121}) is 1 or close to it. One ($P_{11221212}$) is fairly high. P_{112211} depends on mine conditions and could be high. The remaining value ($P_{11221211}$) is, we hope, quite low, close to zero, and thus the product of these four values should also be low. Supposing, however, that the methane detection system was found to be ineffective in a high methane mine, this term could be higher and make a significant contribution to the probability of the top event, a fire originating at the face.

In the next term, corresponding to the third minimum cut set, the first two values in the product are the same as for the previous term and could both be high. The third probability is for an event which is the logical negative of the third term above. Its value is one minus the value used in the term above. If we assume that the methane detection system is effective and that mining operations are properly terminated, then this value will be high as well. The final value is for the probability of an ignition source at the face once the mine has been evacuated and all systems shut down. This should normally be quite low and keep the product for this term low. Otherwise, fires would be unavoidable in mines with high methane levels.

In the final two terms, we again have the high probability of oxygen and the probability of the given combustible material being present, loose coal in the first case and imported flammable materials in the second case. In both cases, we can assign a value of one. Thus, the probability of each of these two terms rests on the final probabilities in their products, that of a suitable source of ignition.

The ignition temperature of coal is relatively high and the generation of sufficient heat is not too likely an event. For imported flammable materials, it is difficult to assign a single probability for a diverse group of materials with different points of ignition. If we restrict our attention to wood, however, which is the major constituent of this group, we can at least say that this probability has a higher value than for loose coal and, thus, deserves greater attention.

From this very simple and superficial example, we can see that the events in this model range from almost certainties to those which should never happen. It is the proper combination of events, with at least one controlling factor in each term, which keeps the probability of the top event low.

The assumption of equal probabilities is clearly not valid in this model and the qualitative analyses which depend on that assumption are not particularly useful in the present study. In almost all cases, the application of such measures must be regarded as preliminary.

3.4 Future Development of the Fault Tree Model

The most valuable results from the model can be achieved only by assigning probability estimates to the primary events and deriving probability values for the top event and its minimum cut sets. This process is often termed "quantifying" the model. A detailed data collection effort is invloved and this is beyond the scope of the current effort. A full quantitative analysis could, however, proceed as outlined below.

A list of the distinct primary events of the model would be prepared. A particular mine would be selected and individuals knowledgeable in the mine characteristics and operations would be consulted in order to arrive at a set of estimates and ranges for the probability of each primary event in the list.

The event numbers in the list of minimal cut set terms would be replaced by the corresponding probability values. The values within each term would be multiplied to obtain the probabilities of all causes of the top event. The probability of the top event can be obtained by summing these probabilities if all the causes are statistically independent. If not, there is an adjusting formula for the sum. Thus, we will have the probability of the top event and each of its causes given the set of primary event probabilities. The causes can be ranked according to their severity as fire hazards.

The top event causes can also be grouped according to combustible materials, heat sources, and mine areas, and group probability sums computed so that the relative probability of fire initiation can be examined over these various categories.

A sensitivity analysis would be performed by evaluating the top event using a range of values for a primary event, holding all others at constant values. The resulting range of values for the top event probability becomes a measure of the sensitivity of the top event to that primary event. Those primary events which show the greatest sensitivity will be the best candidates for remedial action to reduce or at least control the likelihood of the top event.

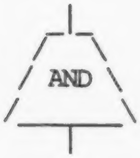
Different sets of primary event probabilities can be used to represent different scenarios of mine operation. For instance, the replacement of some or all wood by non-combustible materials would have the effect of lowering the probability of wood (or imported combustible materials) being present in an area. The replacement of wood by treated wood, could be represented the same way or by lowering the probability of ignition having been reached by a spark, flame or given amount of heat energy. Lowering the temperature of the whole mine would have the effect of decreasing that probability for all materials in all mine areas (since more heat would be required to raise materials to their ignition point). By evaluating the model for these different scenarios, their effect on the overall fire hazards in the mine can be evaluated.

These are only the most basic techniques for quantitatively evaluating a fault tree model. Sophisticated techniques have been developed and would be investigated for application to the coal mine system. For instance "GO" is a technique which expands on the fault tree by introducing a time factor and random variables. Thus, it is not as restrictive in the type of information it uses as are standard fault tree models. Computer programs are available for many of these methods as well as for basic fault tree evaluation.

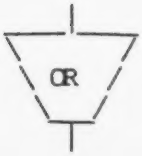
This model deals solely with the origination of a fire in the mine, this being its top event. To deal with related matters such as the propagation of a fire from any origin to a given combustible material such as wood, requires an adaptation of the present model, re-structuring it to place the initiation of fire in wood as the top event and using the present model essentially as a sub-tree. This model could be developed and subject to the same tests as the original.

This model has been designed to be applied in any underground longwall coal mine. We recommend that the application of this methodology to other mining systems and other types of underground mines would be a worthwhile goal.

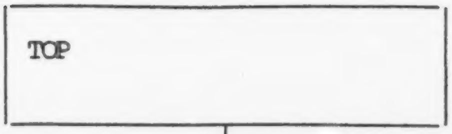
Figure 1. Fault Tree model of a coal mine. Key to symbols is as follows:



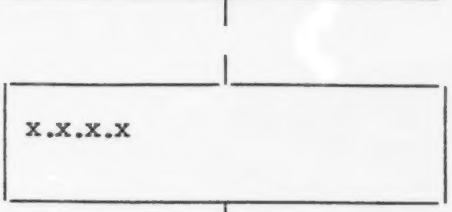
AND Gate



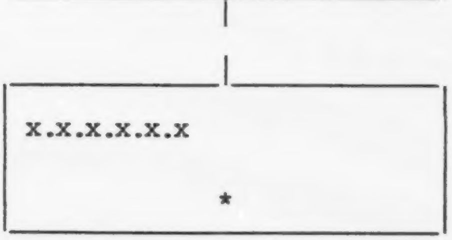
OR Gate



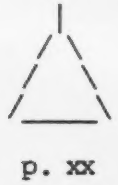
TOP Event



Intermediate Event (number x.x.x.x)



Terminal Event (number x.x.x.x.x.x)



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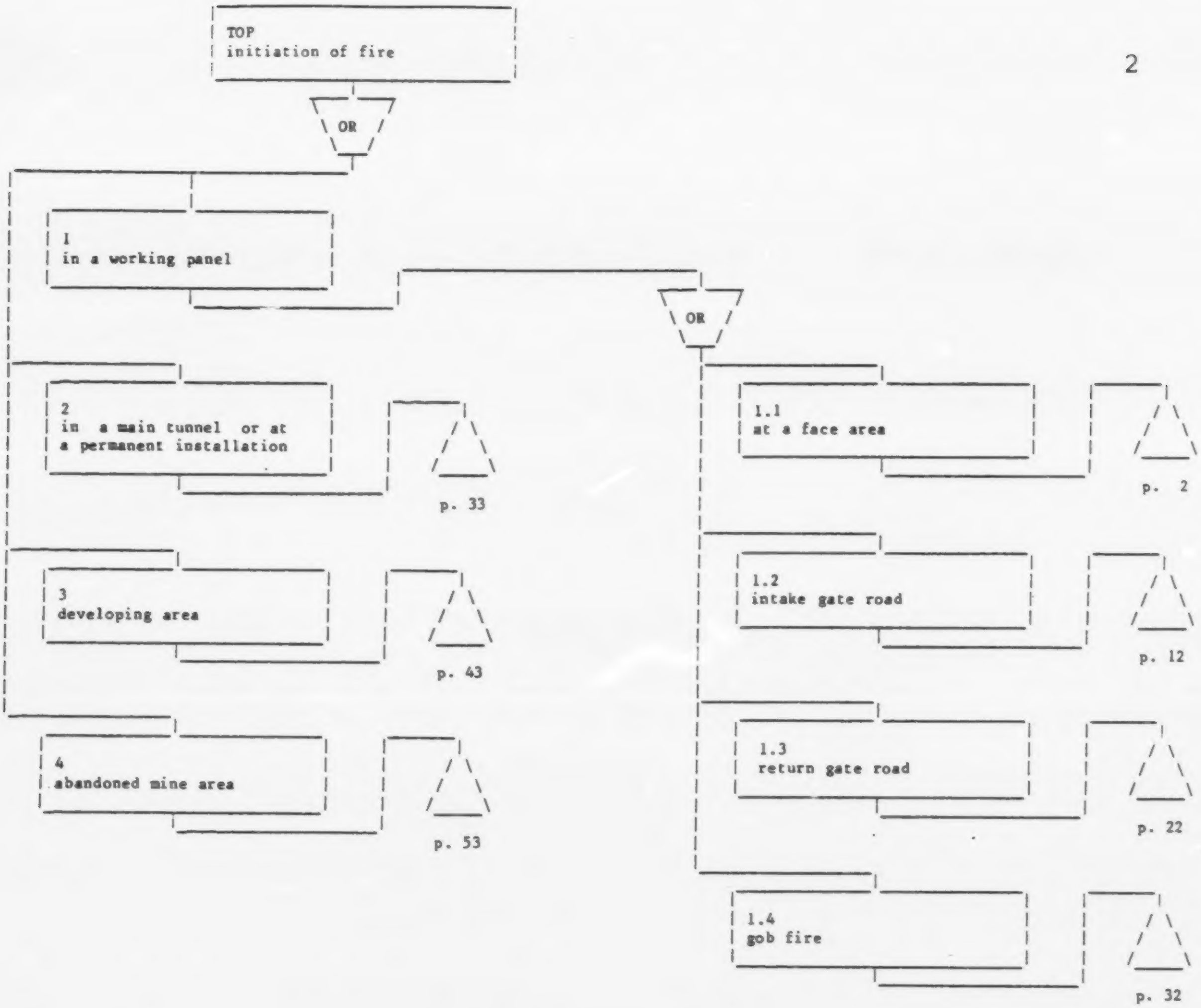
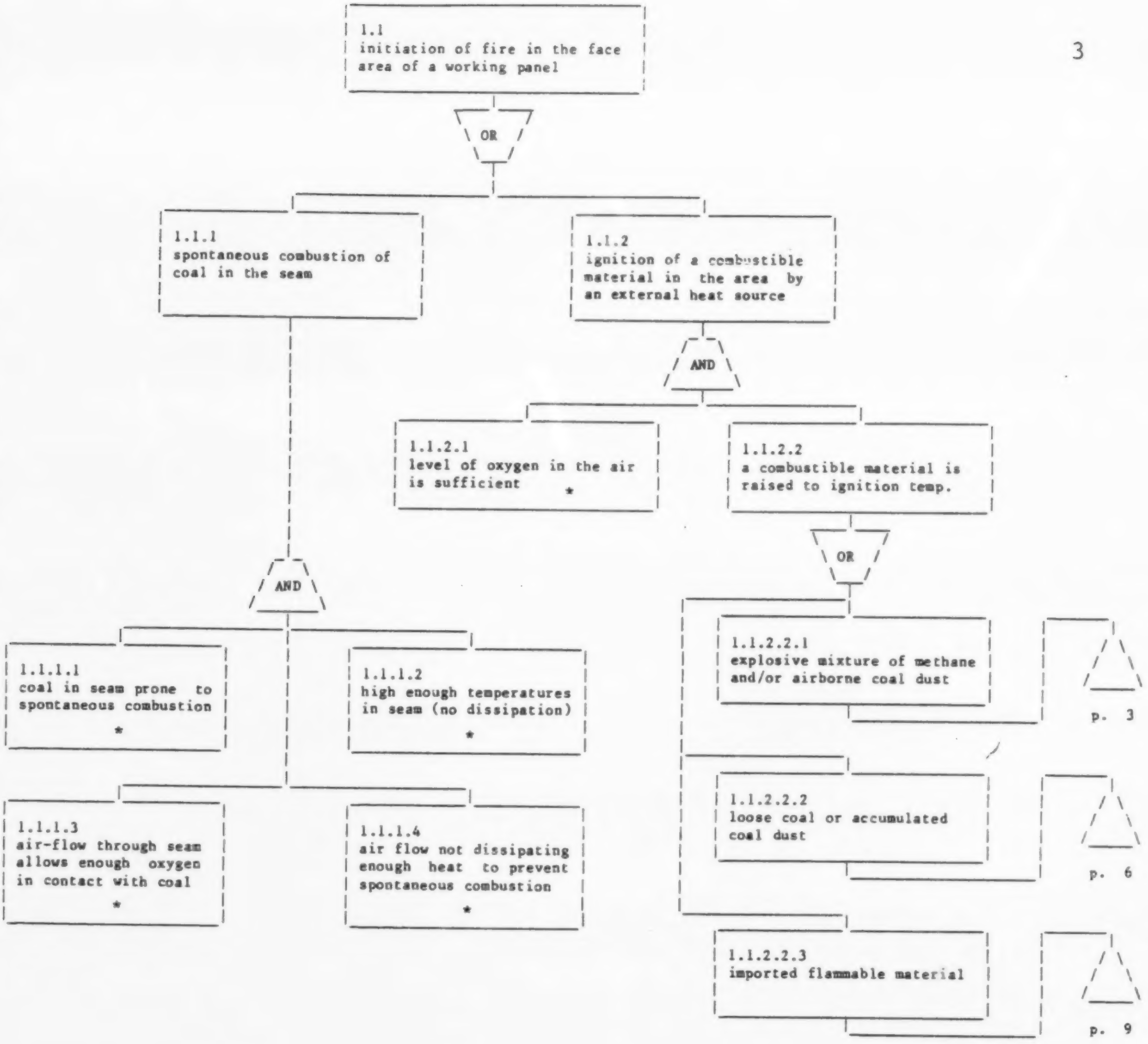
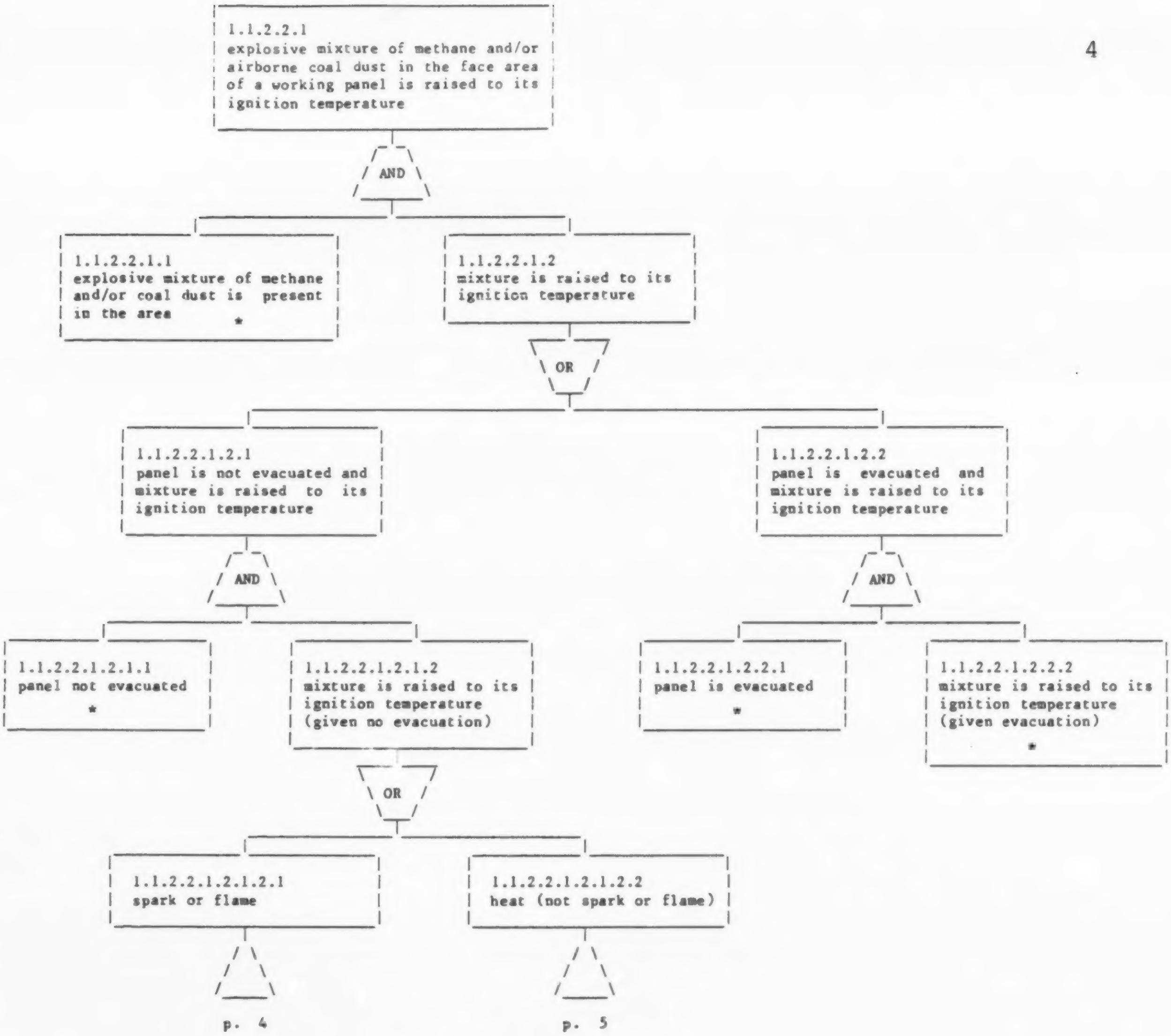

TOP
initiation of fire
OR
1
in a working panel
OR
2
in a main tunnel or at a permanent installation
p. 33
3
developing area
p. 43
4
abandoned mine area
p. 53
1.1
at a face area
p. 2
1.2
intake gate road
p. 12
1.3
return gate road
p. 22
1.4
gob fire
p. 32


1.1
initiation of fire in the face area of a working panel
OR
1.1.1
spontaneous combustion of coal in the seam
1.1.2
ignition of a combustible material in the area by an external heat source
AND
1.1.2.1
level of oxygen in the air is sufficient
*
1.1.2.2
a combustible material is raised to ignition temp.
OR
AND
1.1.2.2.1
explosive mixture of methane and/or airborne coal dust
p. 3
1.1.1.1
coal in seam prone to spontaneous combustion
*
1.1.1.2
high enough temperatures in seam (no dissipation)
*
1.1.2.2.2
loose coal or accumulated coal dust
p. 6
1.1.1.3
air-flow through seam allows enough oxygen in contact with coal
*
1.1.1.4
air flow not dissipating enough heat to prevent spontaneous combustion
*
1.1.2.2.3
imported flammable material
p. 9



1.1.2.2.1
explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition temperature

1.1.2.2.1.1
explosive mixture of methane and/or coal dust is present in the area *

1.1.2.2.1.2
mixture is raised to its ignition temperature

1.1.2.2.1.2.1
panel is not evacuated and mixture is raised to its ignition temperature

1.1.2.2.1.2.2
panel is evacuated and mixture is raised to its ignition temperature

1.1.2.2.1.2.1.1
panel not evacuated *

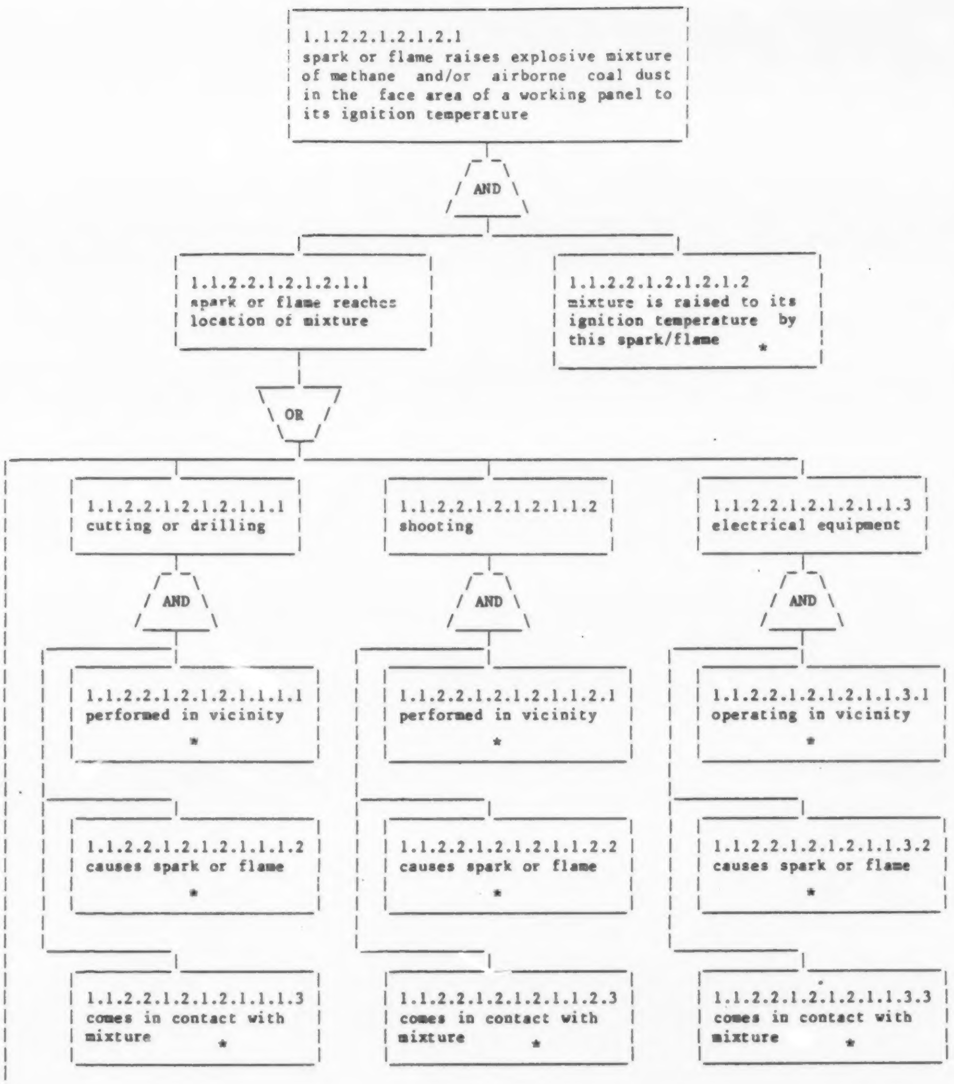
1.1.2.2.1.2.1.2
mixture is raised to its ignition temperature (given no evacuation)

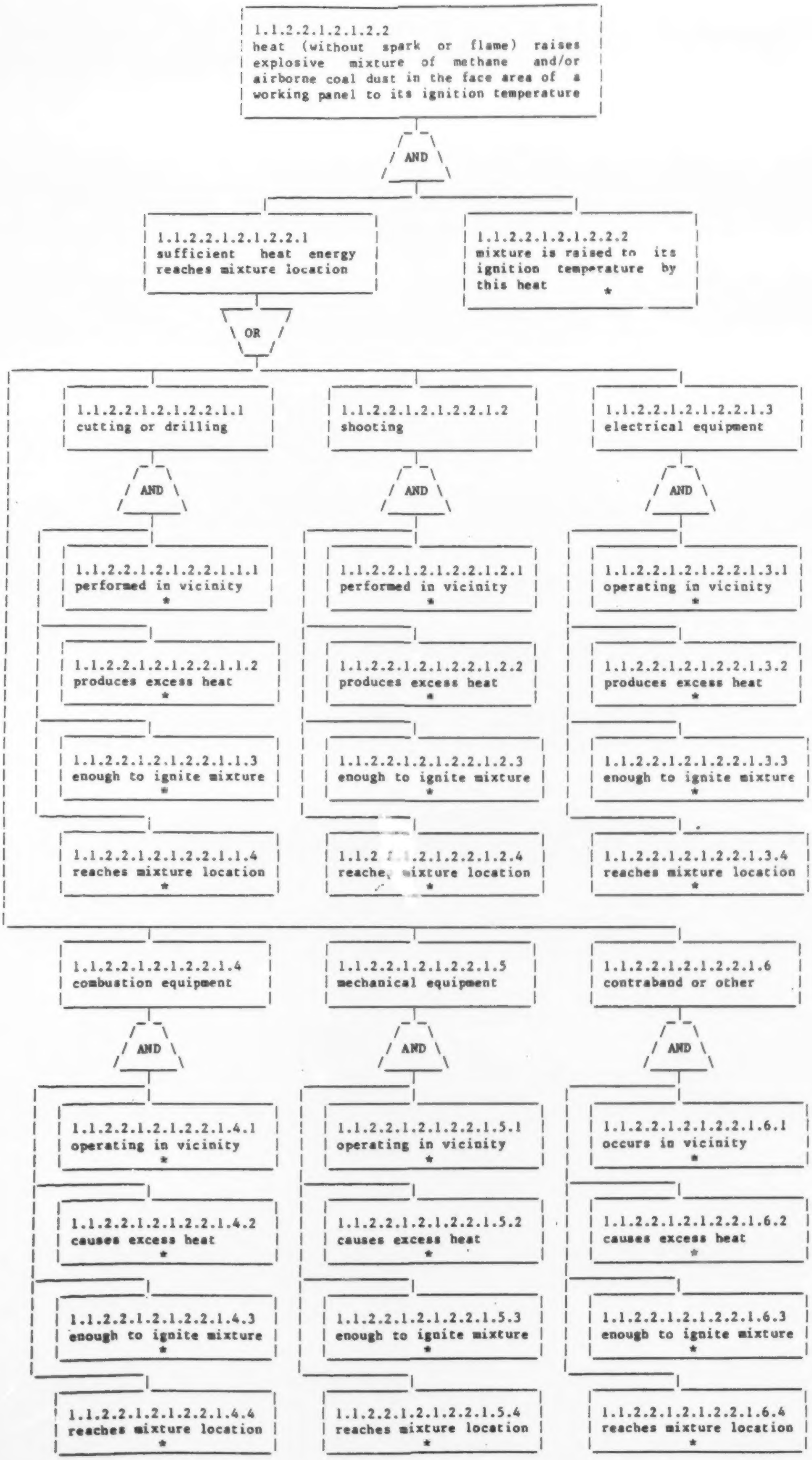
1.1.2.2.1.2.2.1
panel is evacuated *

1.1.2.2.1.2.2.2
mixture is raised to its ignition temperature (given evacuation) *

1.1.2.2.1.2.1.2.1
spark or flame

1.1.2.2.1.2.1.2.2
heat (not spark or flame)


1.1.2.2.1.2.1.2.1
spark or flame raises explosive mixture of methane and/or airborne coal dust in the face area of a working panel to its ignition temperature
AND
1.1.2.2.1.2.1.2.1.1
spark or flame reaches location of mixture
1.1.2.2.1.2.1.2.1.2
mixture is raised to its ignition temperature by this spark/flame *
OR
1.1.2.2.1.2.1.2.1.1.1
cutting or drilling
1.1.2.2.1.2.1.2.1.1.2
shooting
1.1.2.2.1.2.1.2.1.1.3
electrical equipment
AND
AND
AND
1.1.2.2.1.2.1.2.1.1.1.1
performed in vicinity *
1.1.2.2.1.2.1.2.1.1.2.1
performed in vicinity *
1.1.2.2.1.2.1.2.1.1.3.1
operating in vicinity *
1.1.2.2.1.2.1.2.1.1.1.2
causes spark or flame *
1.1.2.2.1.2.1.2.1.1.2.2
causes spark or flame *
1.1.2.2.1.2.1.2.1.1.3.2
causes spark or flame *
1.1.2.2.1.2.1.2.1.1.1.3
comes in contact with mixture *
1.1.2.2.1.2.1.2.1.1.2.3
comes in contact with mixture *
1.1.2.2.1.2.1.2.1.1.3.3
comes in contact with mixture *
1.1.2.2.1.2.1.2.1.1.4
combustion equipment
1.1.2.2.1.2.1.2.1.1.5
mechanical equipment
1.1.2.2.1.2.1.2.1.1.6
contraband or other
AND
AND
AND
1.1.2.2.1.2.1.2.1.1.4.1
operating in vicinity *
1.1.2.2.1.2.1.2.1.1.5.1
operating in vicinity *
1.1.2.2.1.2.1.2.1.1.6.1
occurs in vicinity *
1.1.2.2.1.2.1.2.1.1.4.2
causes spark or flame *
1.1.2.2.1.2.1.2.1.1.5.2
causes spark or flame *
1.1.2.2.1.2.1.2.1.1.6.2
causes spark or flame *
1.1.2.2.1.2.1.2.1.1.4.3
comes in contact with mixture *
1.1.2.2.1.2.1.2.1.1.5.3
comes in contact with mixture *
1.1.2.2.1.2.1.2.1.1.6.3
comes in contact with mixture *


1.1.2.2.1.2.1.2.2
heat (without spark or flame) raises explosive mixture of methane and/or airborne coal dust in the face area of a working panel to its ignition temperature
AND
1.1.2.2.1.2.1.2.2.1
sufficient heat energy reaches mixture location
1.1.2.2.1.2.1.2.2.2
mixture is raised to its ignition temperature by this heat
*
OR
1.1.2.2.1.2.1.2.2.1.1
cutting or drilling
1.1.2.2.1.2.1.2.2.1.2
shooting
1.1.2.2.1.2.1.2.2.1.3
electrical equipment
AND
AND
AND
1.1.2.2.1.2.1.2.2.1.1.1
performed in vicinity
*
1.1.2.2.1.2.1.2.2.1.1.2
produces excess heat
*
1.1.2.2.1.2.1.2.2.1.1.3
enough to ignite mixture
*
1.1.2.2.1.2.1.2.2.1.1.4
reaches mixture location
*
1.1.2.2.1.2.1.2.2.1.2.1
performed in vicinity
*
1.1.2.2.1.2.1.2.2.1.2.2
produces excess heat
*
1.1.2.2.1.2.1.2.2.1.2.3
enough to ignite mixture
*
1.1.2.2.1.2.1.2.2.1.2.4
reaches mixture location
*
1.1.2.2.1.2.1.2.2.1.3.1
operating in vicinity
*
1.1.2.2.1.2.1.2.2.1.3.2
produces excess heat
*
1.1.2.2.1.2.1.2.2.1.3.3
enough to ignite mixture
*
1.1.2.2.1.2.1.2.2.1.3.4
reaches mixture location
*
1.1.2.2.1.2.1.2.2.1.4
combustion equipment
1.1.2.2.1.2.1.2.2.1.5
mechanical equipment
1.1.2.2.1.2.1.2.2.1.6
contraband or other
AND
AND
AND
1.1.2.2.1.2.1.2.2.1.4.1
operating in vicinity
*
1.1.2.2.1.2.1.2.2.1.4.2
causes excess heat
*
1.1.2.2.1.2.1.2.2.1.4.3
enough to ignite mixture
*
1.1.2.2.1.2.1.2.2.1.4.4
reaches mixture location
*
1.1.2.2.1.2.1.2.2.1.5.1
operating in vicinity
*
1.1.2.2.1.2.1.2.2.1.5.2
causes excess heat
*
1.1.2.2.1.2.1.2.2.1.5.3
enough to ignite mixture
*
1.1.2.2.1.2.1.2.2.1.5.4
reaches mixture location
*
1.1.2.2.1.2.1.2.2.1.6.1
occurs in vicinity
*
1.1.2.2.1.2.1.2.2.1.6.2
causes excess heat
*
1.1.2.2.1.2.1.2.2.1.6.3
enough to ignite mixture
*
1.1.2.2.1.2.1.2.2.1.6.4
reaches mixture location
*

```
                   ______________________________________
                  |                                      |
                  | 1.1.2.2.2                            |
                  | loose  coal  or  accumulated  coal   |
                  | dust in the face area of a working   |
                  | panel  is raised to  its  ignition   |
                  | temperature                          |
                  |______________________________________|
                                    |
                                  /---\
                                 / AND \
                                /_______\
                                    |
           _________________________|_____________________
    ______|________________________            ___________|______________
   |                               |          |                          |
   | 1.1.2.2.2.1                   |          | 1.1.2.2.2.2              |
   | loose coal or accumulated     |          | coal   is  raised  to its|
   | coal dust is  present  in     |          | ignition temperature     |
   | the area          *           |          |__________________________|
   |_______________________________|                      |
                                                     \-----------/
                                                      \  OR    /
                                                       \______/
                                                           |
                               ____________________________|____________
                ______________|_____________           ____________|_____________
               |                            |         |                           |
               |  1.1.2.2.2.2.1             |         |  1.1.2.2.2.2.2            |
               |  spark or flame            |         |  heat (not spark or flame)|
               |____________________________|         |___________________________|
                             |                                      |
                            / \                                    / \
                           /   \                                  /   \
                          /_____\                                /_____\

                           p.  7                                  p.  8
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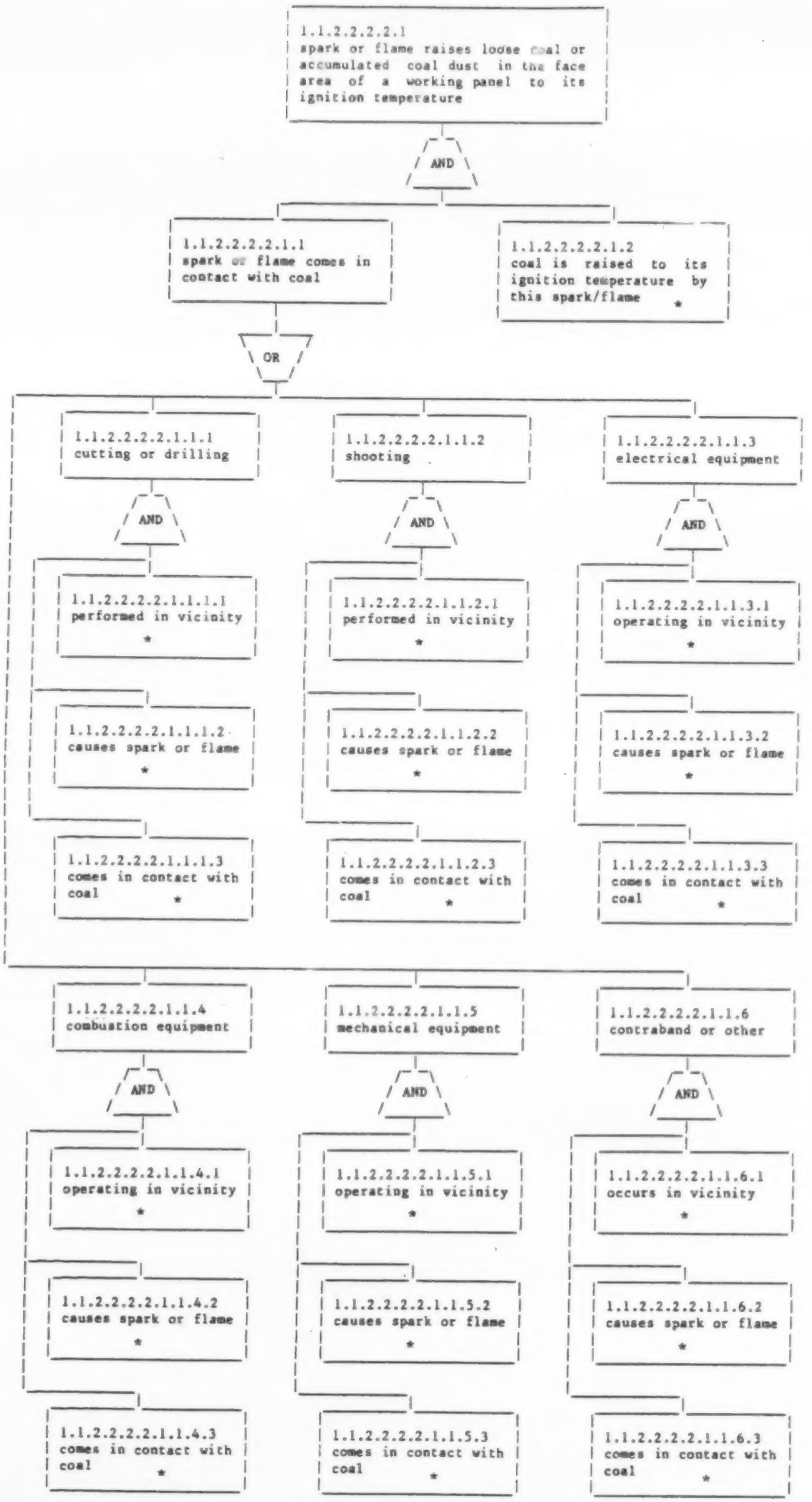
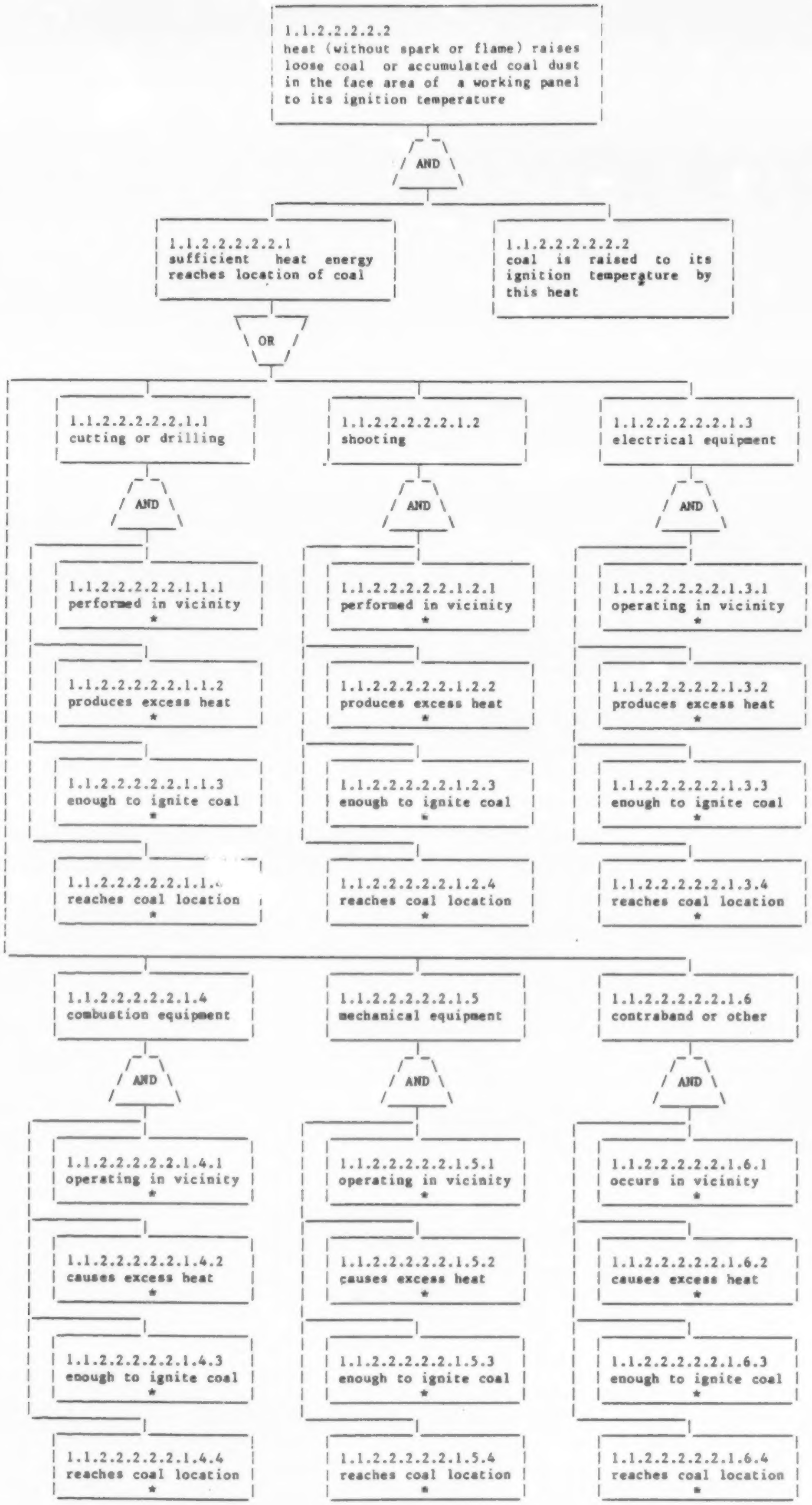
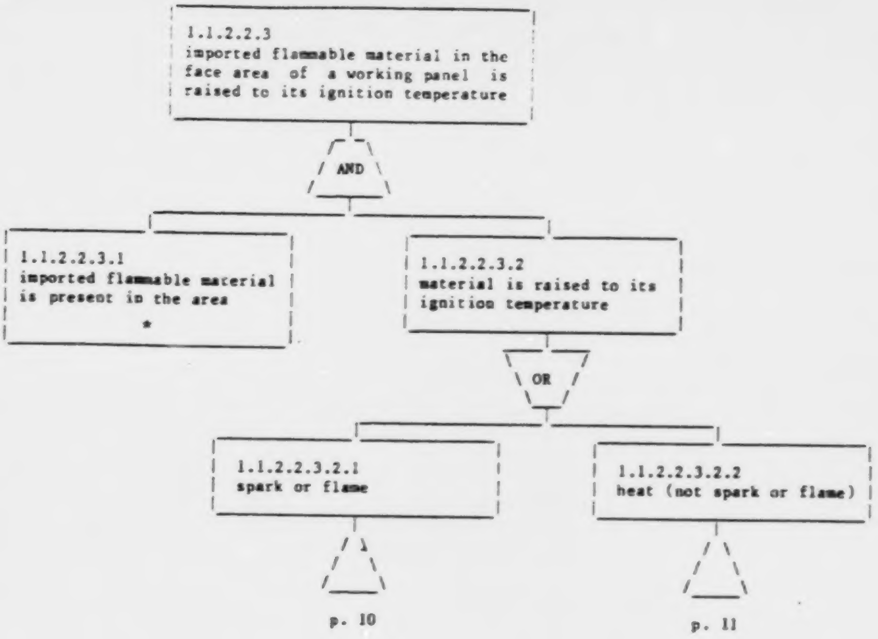
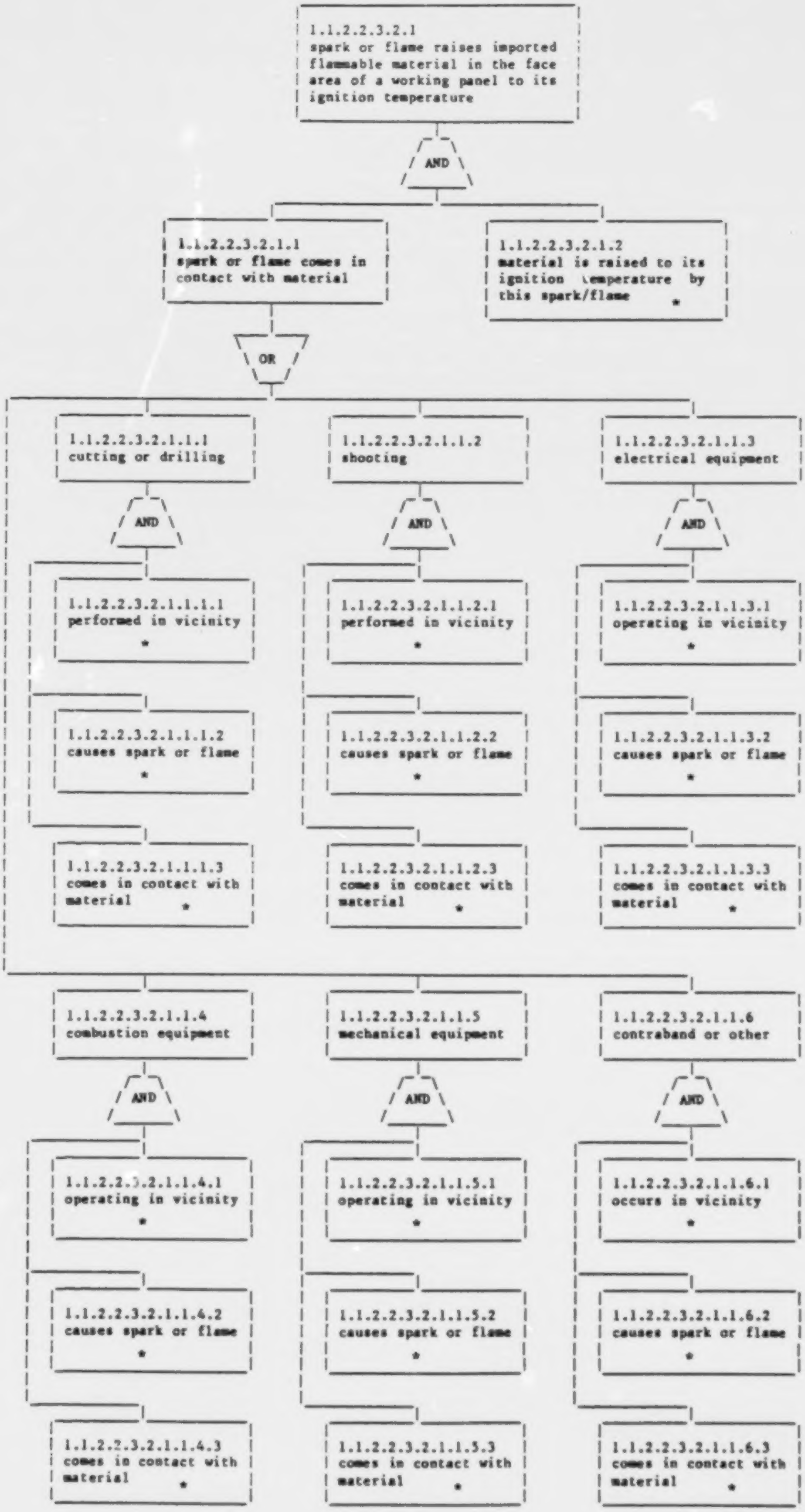
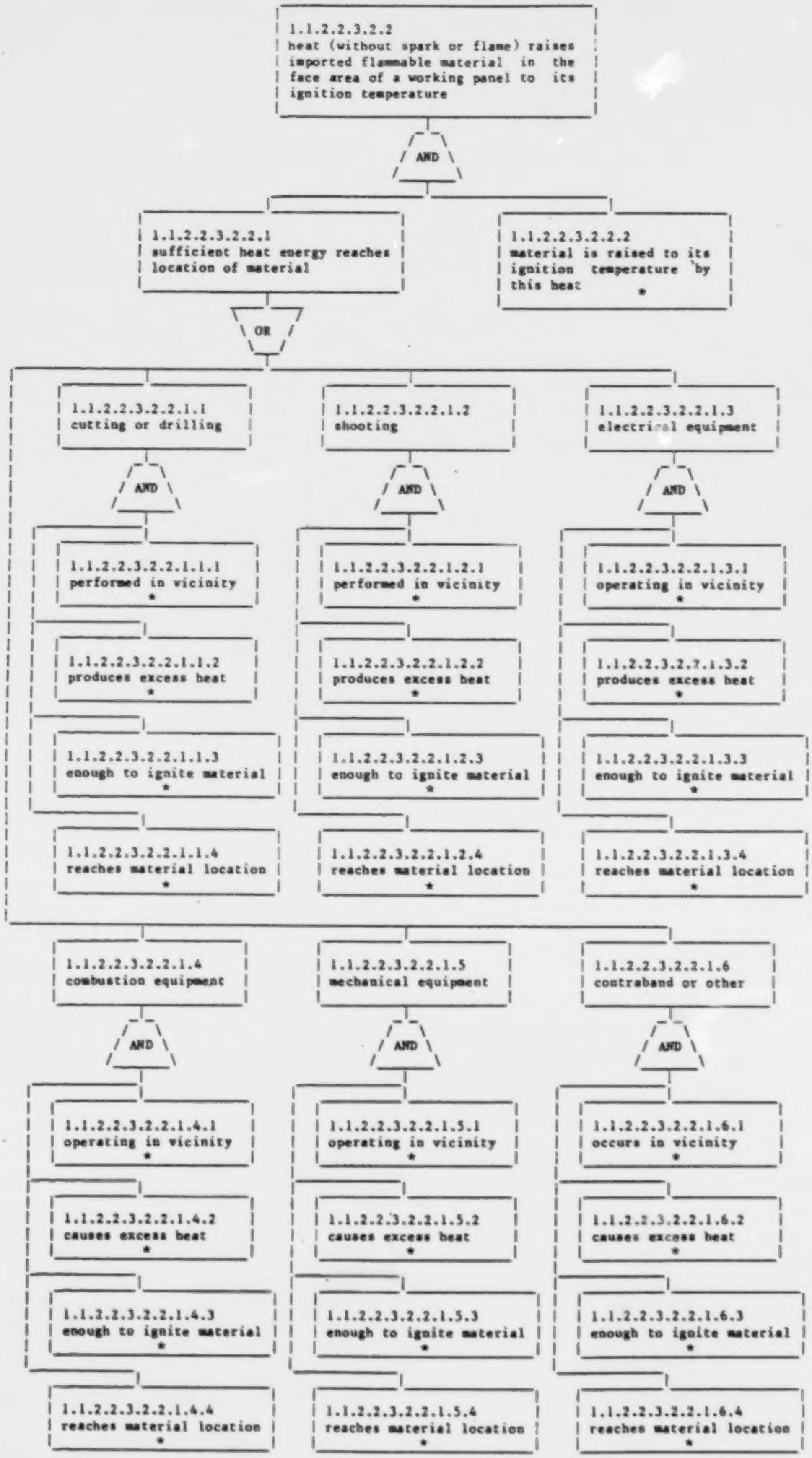
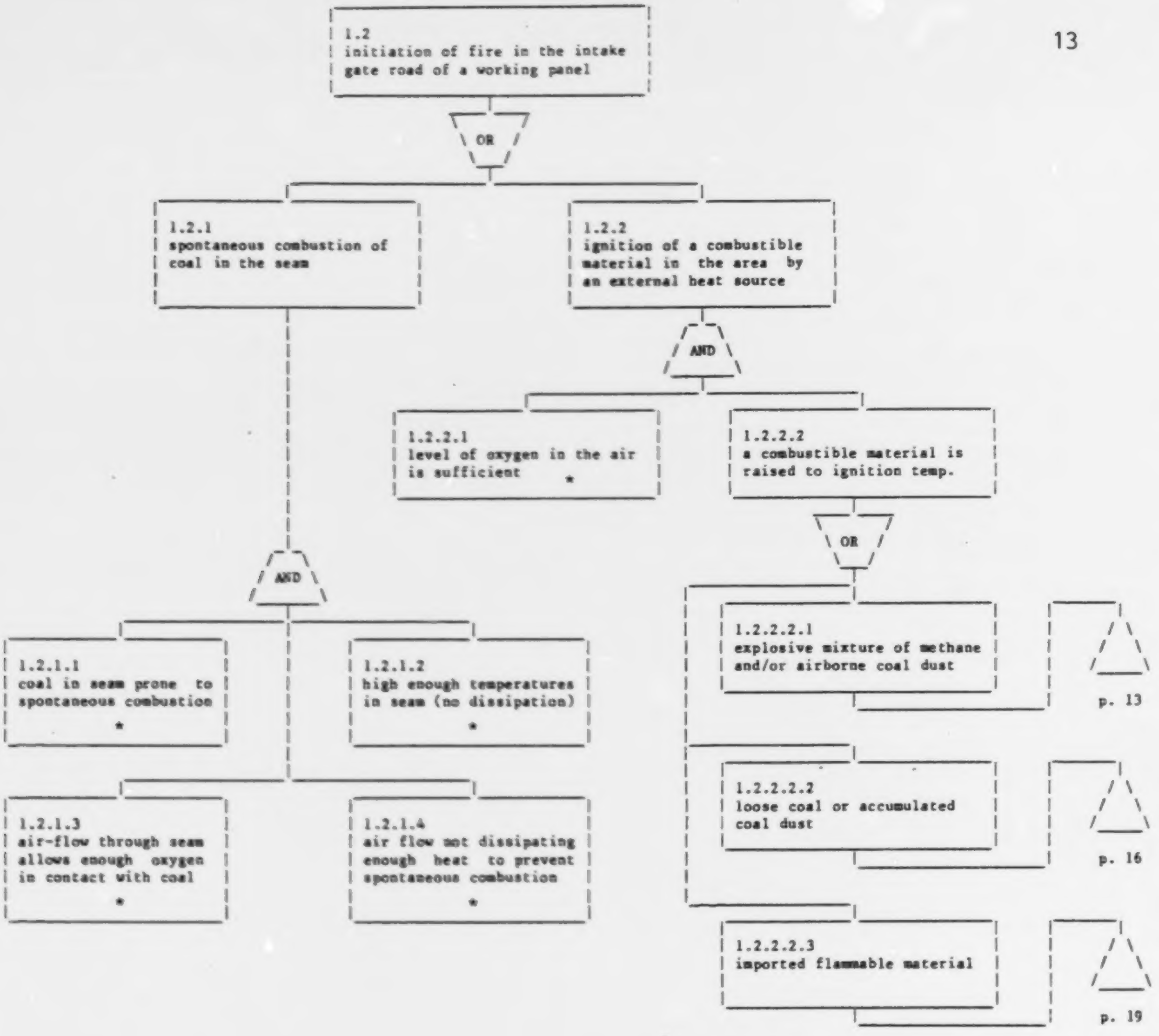

1.1.2.2.2.2.1
spark or flame raises loose coal or accumulated coal dust in the face area of a working panel to its ignition temperature
AND
1.1.2.2.2.2.1.1
spark or flame comes in contact with coal
1.1.2.2.2.2.1.2
coal is raised to its ignition temperature by this spark/flame *
OR
1.1.2.2.2.2.1.1.1
cutting or drilling
1.1.2.2.2.2.1.1.2
shooting
1.1.2.2.2.2.1.1.3
electrical equipment
AND
AND
AND
1.1.2.2.2.2.1.1.1.1
performed in vicinity *
1.1.2.2.2.2.1.1.2.1
performed in vicinity *
1.1.2.2.2.2.1.1.3.1
operating in vicinity *
1.1.2.2.2.2.1.1.1.2
causes spark or flame *
1.1.2.2.2.2.1.1.2.2
causes spark or flame *
1.1.2.2.2.2.1.1.3.2
causes spark or flame *
1.1.2.2.2.2.1.1.1.3
comes in contact with coal *
1.1.2.2.2.2.1.1.2.3
comes in contact with coal *
1.1.2.2.2.2.1.1.3.3
comes in contact with coal *
1.1.2.2.2.2.1.1.4
combustion equipment
1.1.2.2.2.2.1.1.5
mechanical equipment
1.1.2.2.2.2.1.1.6
contraband or other
AND
AND
AND
1.1.2.2.2.2.1.1.4.1
operating in vicinity *
1.1.2.2.2.2.1.1.5.1
operating in vicinity *
1.1.2.2.2.2.1.1.6.1
occurs in vicinity *
1.1.2.2.2.2.1.1.4.2
causes spark or flame *
1.1.2.2.2.2.1.1.5.2
causes spark or flame *
1.1.2.2.2.2.1.1.6.2
causes spark or flame *
1.1.2.2.2.2.1.1.4.3
comes in contact with coal *
1.1.2.2.2.2.1.1.5.3
comes in contact with coal *
1.1.2.2.2.2.1.1.6.3
comes in contact with coal *

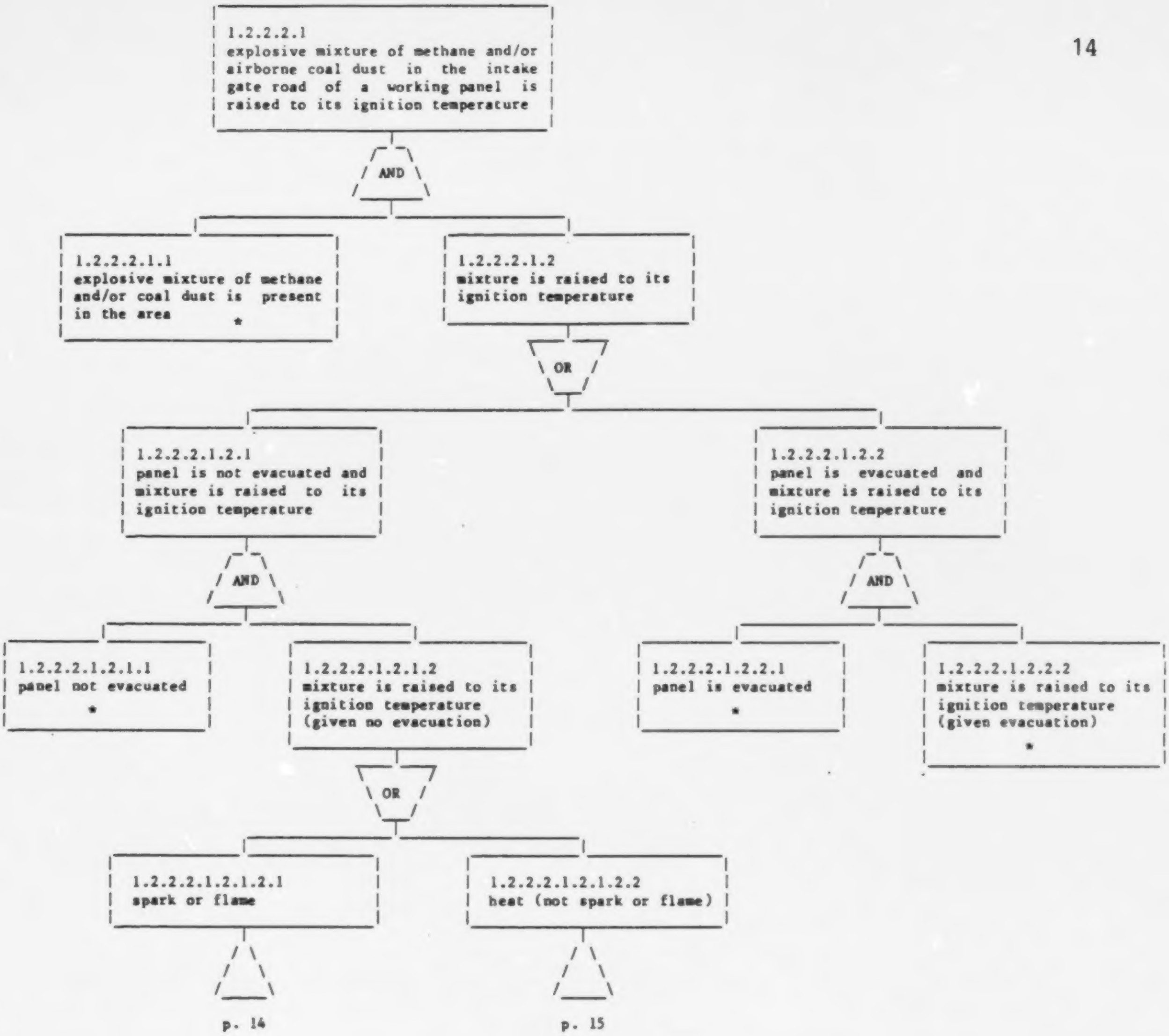

1.1.2.2.2.2.2 heat (without spark or flame) raises loose coal or accumulated coal dust in the face area of a working panel to its ignition temperature
AND
1.1.2.2.2.2.2.1 sufficient heat energy reaches location of coal
1.1.2.2.2.2.2.2 coal is raised to its ignition temperature by this heat
OR
1.1.2.2.2.2.2.1.1 cutting or drilling
1.1.2.2.2.2.2.1.2 shooting
1.1.2.2.2.2.2.1.3 electrical equipment
AND
AND
AND
1.1.2.2.2.2.2.1.1.1 performed in vicinity *
1.1.2.2.2.2.2.1.1.2 produces excess heat *
1.1.2.2.2.2.2.1.1.3 enough to ignite coal *
1.1.2.2.2.2.2.1.1. reaches coal location *
1.1.2.2.2.2.2.1.2.1 performed in vicinity *
1.1.2.2.2.2.2.1.2.2 produces excess heat *
1.1.2.2.2.2.2.1.2.3 enough to ignite coal *
1.1.2.2.2.2.2.1.2.4 reaches coal location *
1.1.2.2.2.2.2.1.3.1 operating in vicinity *
1.1.2.2.2.2.2.1.3.2 produces excess heat *
1.1.2.2.2.2.2.1.3.3 enough to ignite coal *
1.1.2.2.2.2.2.1.3.4 reaches coal location *
1.1.2.2.2.2.2.1.4 combustion equipment
1.1.2.2.2.2.2.1.5 mechanical equipment
1.1.2.2.2.2.2.1.6 contraband or other
AND
AND
AND
1.1.2.2.2.2.2.1.4.1 operating in vicinity *
1.1.2.2.2.2.2.1.4.2 causes excess heat *
1.1.2.2.2.2.2.1.4.3 enough to ignite coal *
1.1.2.2.2.2.2.1.4.4 reaches coal location *
1.1.2.2.2.2.2.1.5.1 operating in vicinity *
1.1.2.2.2.2.2.1.5.2 causes excess heat *
1.1.2.2.2.2.2.1.5.3 enough to ignite coal *
1.1.2.2.2.2.2.1.5.4 reaches coal location *
1.1.2.2.2.2.2.1.6.1 occurs in vicinity *
1.1.2.2.2.2.2.1.6.2 causes excess heat *
1.1.2.2.2.2.2.1.6.3 enough to ignite coal *
1.1.2.2.2.2.2.1.6.4 reaches coal location *

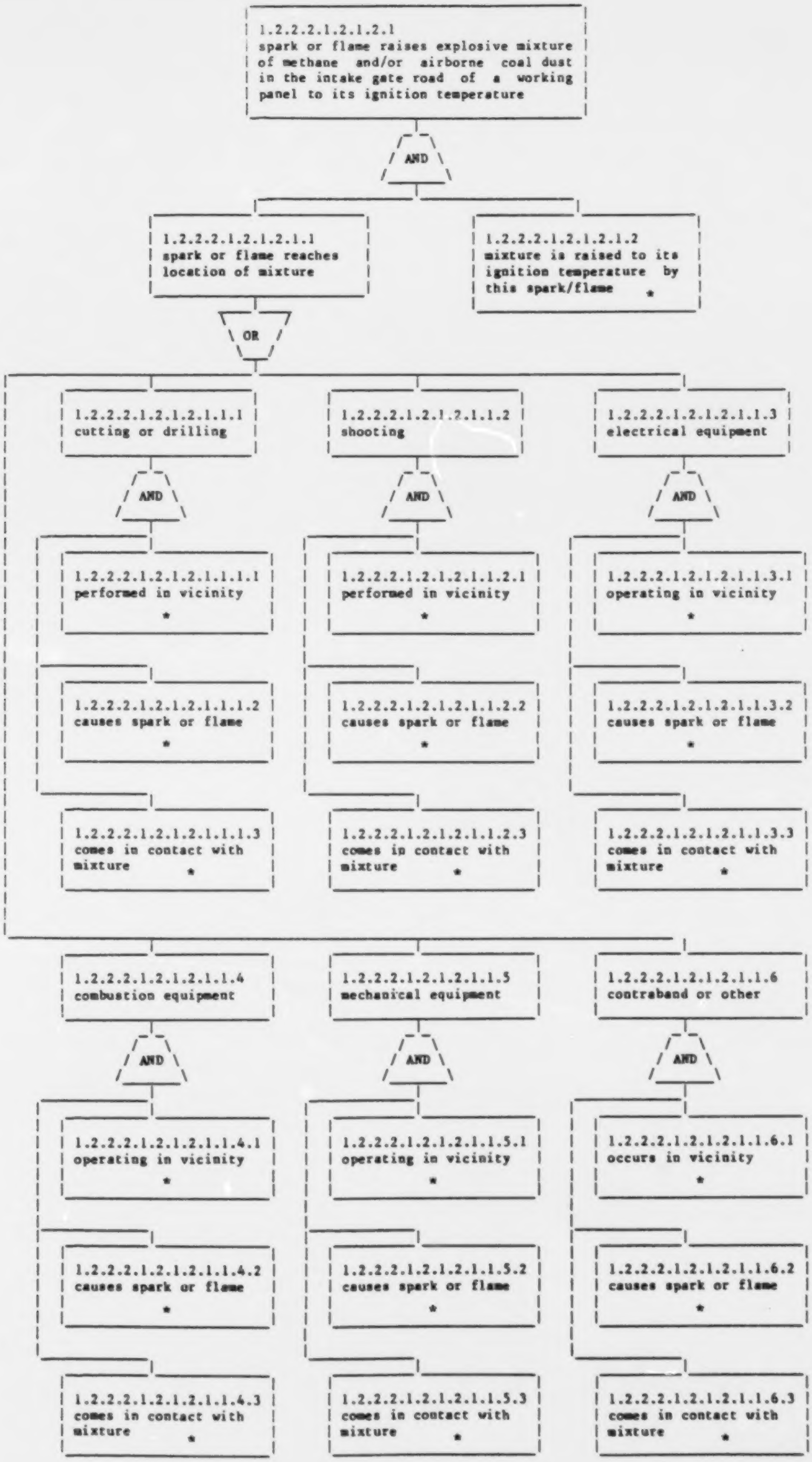

1.1.2.2.3
imported flammable material in the face area of a working panel is raised to its ignition temperature
AND
1.1.2.2.3.1
imported flammable material is present in the area
*
1.1.2.2.3.2
material is raised to its ignition temperature
OR
1.1.2.2.3.2.1
spark or flame
1.1.2.2.3.2.2
heat (not spark or flame)
p. 10
p. 11

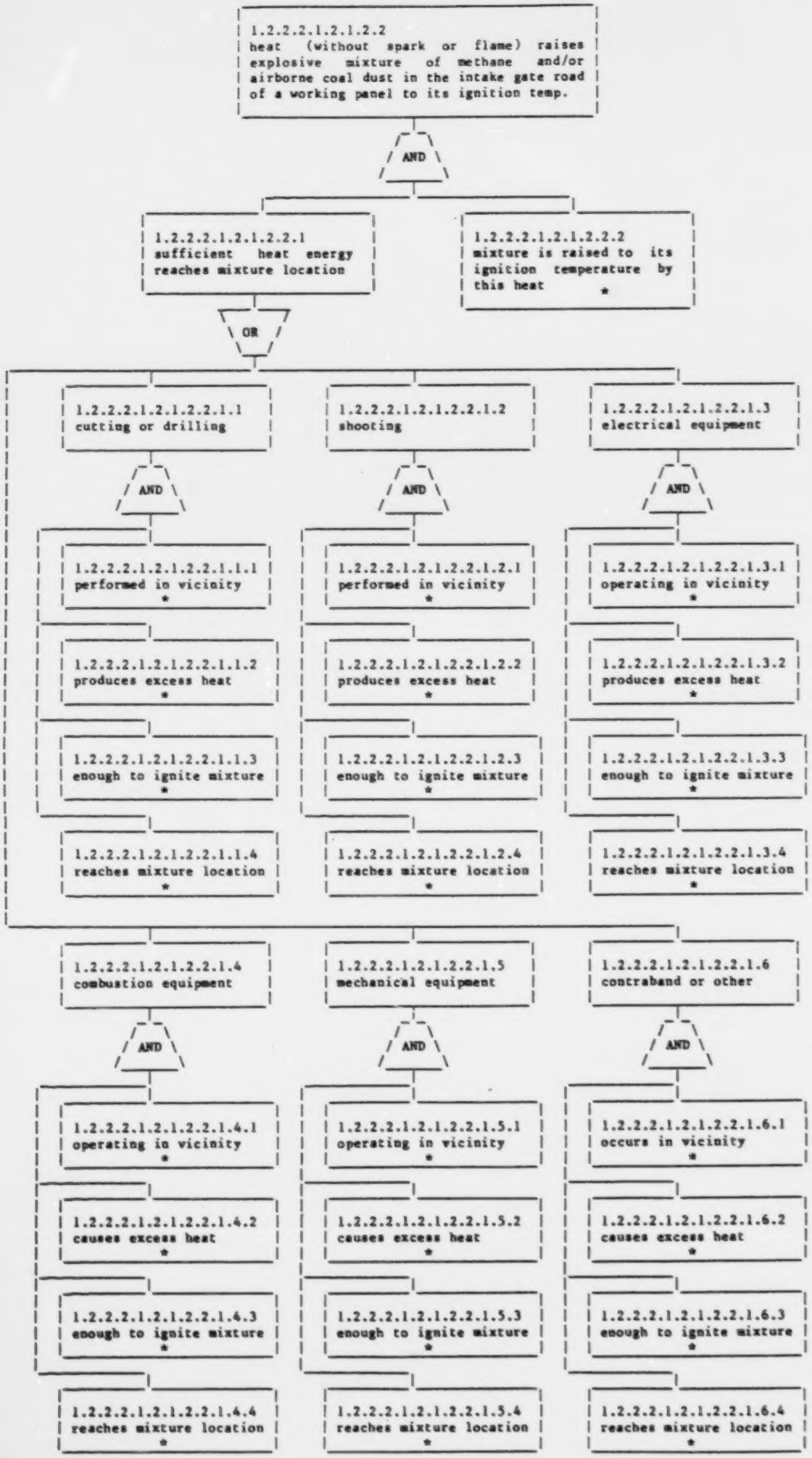

1.1.2.2.3.2.1
spark or flame raises imported flammable material in the face area of a working panel to its ignition temperature
AND
1.1.2.2.3.2.1.1
spark or flame comes in contact with material
1.1.2.2.3.2.1.2
material is raised to its ignition temperature by this spark/flame *
OR
1.1.2.2.3.2.1.1.1
cutting or drilling
1.1.2.2.3.2.1.1.2
shooting
1.1.2.2.3.2.1.1.3
electrical equipment
AND
AND
AND
1.1.2.2.3.2.1.1.1.1
performed in vicinity *
1.1.2.2.3.2.1.1.2.1
performed in vicinity *
1.1.2.2.3.2.1.1.3.1
operating in vicinity *
1.1.2.2.3.2.1.1.1.2
causes spark or flame *
1.1.2.2.3.2.1.1.2.2
causes spark or flame *
1.1.2.2.3.2.1.1.3.2
causes spark or flame *
1.1.2.2.3.2.1.1.1.3
comes in contact with material *
1.1.2.2.3.2.1.1.2.3
comes in contact with material *
1.1.2.2.3.2.1.1.3.3
comes in contact with material *
1.1.2.2.3.2.1.1.4
combustion equipment
1.1.2.2.3.2.1.1.5
mechanical equipment
1.1.2.2.3.2.1.1.6
contraband or other
AND
AND
AND
1.1.2.2.3.2.1.1.4.1
operating in vicinity *
1.1.2.2.3.2.1.1.5.1
operating in vicinity *
1.1.2.2.3.2.1.1.6.1
occurs in vicinity *
1.1.2.2.3.2.1.1.4.2
causes spark or flame *
1.1.2.2.3.2.1.1.5.2
causes spark or flame *
1.1.2.2.3.2.1.1.6.2
causes spark or flame *
1.1.2.2.3.2.1.1.4.3
comes in contact with material *
1.1.2.2.3.2.1.1.5.3
comes in contact with material *
1.1.2.2.3.2.1.1.6.3
comes in contact with material *

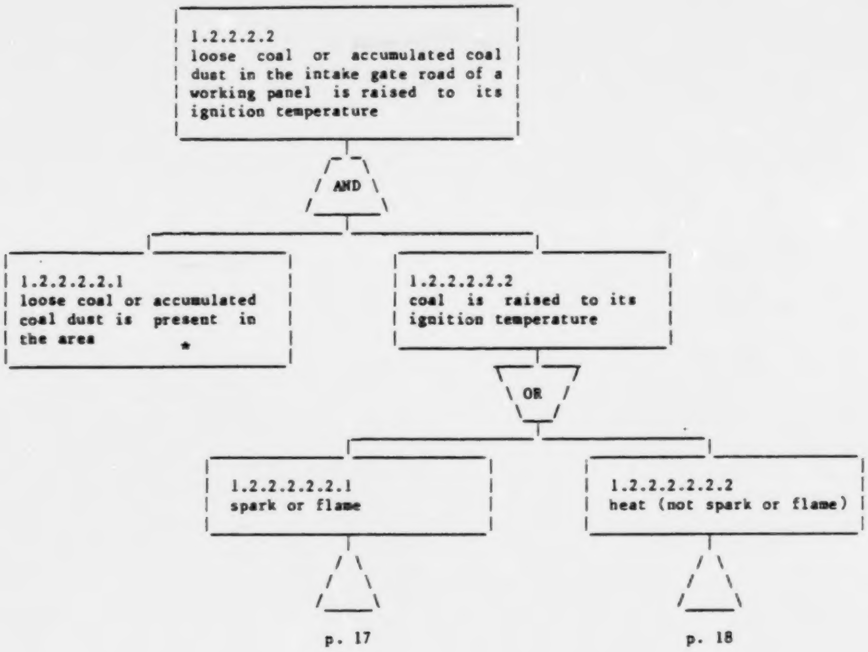

1.1.2.2.3.2.2
heat (without spark or flame) raises imported flammable material in the face area of a working panel to its ignition temperature
AND
1.1.2.2.3.2.2.1
sufficient heat energy reaches location of material
1.1.2.2.3.2.2.2
material is raised to its ignition temperature by this heat
*
OR
1.1.2.2.3.2.2.1.1
cutting or drilling
1.1.2.2.3.2.2.1.2
shooting
1.1.2.2.3.2.2.1.3
electrical equipment
AND
AND
AND
1.1.2.2.3.2.2.1.1.1
performed in vicinity
*
1.1.2.2.3.2.2.1.2.1
performed in vicinity
*
1.1.2.2.3.2.2.1.3.1
operating in vicinity
*
1.1.2.2.3.2.2.1.1.2
produces excess heat
*
1.1.2.2.3.2.2.1.2.2
produces excess heat
*
1.1.2.2.3.2.2.1.3.2
produces excess heat
*
1.1.2.2.3.2.2.1.1.3
enough to ignite material
*
1.1.2.2.3.2.2.1.2.3
enough to ignite material
*
1.1.2.2.3.2.2.1.3.3
enough to ignite material
*
1.1.2.2.3.2.2.1.1.4
reaches material location
*
1.1.2.2.3.2.2.1.2.4
reaches material location
*
1.1.2.2.3.2.2.1.3.4
reaches material location
*
1.1.2.2.3.2.2.1.4
combustion equipment
1.1.2.2.3.2.2.1.5
mechanical equipment
1.1.2.2.3.2.2.1.6
contraband or other
AND
AND
AND
1.1.2.2.3.2.2.1.4.1
operating in vicinity
*
1.1.2.2.3.2.2.1.5.1
operating in vicinity
*
1.1.2.2.3.2.2.1.6.1
occurs in vicinity
*
1.1.2.2.3.2.2.1.4.2
causes excess heat
*
1.1.2.2.3.2.2.1.5.2
causes excess heat
*
1.1.2.2.3.2.2.1.6.2
causes excess heat
*
1.1.2.2.3.2.2.1.4.3
enough to ignite material
*
1.1.2.2.3.2.2.1.5.3
enough to ignite material
*
1.1.2.2.3.2.2.1.6.3
enough to ignite material
*
1.1.2.2.3.2.2.1.4.4
reaches material location
*
1.1.2.2.3.2.2.1.5.4
reaches material location
*
1.1.2.2.3.2.2.1.6.4
reaches material location
*


1.2
initiation of fire in the intake gate road of a working panel
OR
1.2.1
spontaneous combustion of coal in the seam
1.2.2
ignition of a combustible material in the area by an external heat source
AND
1.2.2.1
level of oxygen in the air is sufficient
*
1.2.2.2
a combustible material is raised to ignition temp.
OR
AND
1.2.1.1
coal in seam prone to spontaneous combustion
*
1.2.1.2
high enough temperatures in seam (no dissipation)
*
1.2.1.3
air-flow through seam allows enough oxygen in contact with coal
*
1.2.1.4
air flow not dissipating enough heat to prevent spontaneous combustion
*
1.2.2.2.1
explosive mixture of methane and/or airborne coal dust
p. 13
1.2.2.2.2
loose coal or accumulated coal dust
p. 16
1.2.2.2.3
imported flammable material
p. 19


1.2.2.2.1
explosive mixture of methane and/or airborne coal dust in the intake gate road of a working panel is raised to its ignition temperature
AND
1.2.2.2.1.1
explosive mixture of methane and/or coal dust is present in the area
*
1.2.2.2.1.2
mixture is raised to its ignition temperature
OR
1.2.2.2.1.2.1
panel is not evacuated and mixture is raised to its ignition temperature
AND
1.2.2.2.1.2.2
panel is evacuated and mixture is raised to its ignition temperature
AND
1.2.2.2.1.2.1.1
panel not evacuated
*
1.2.2.2.1.2.1.2
mixture is raised to its ignition temperature (given no evacuation)
OR
1.2.2.2.1.2.2.1
panel is evacuated
*
1.2.2.2.1.2.2.2
mixture is raised to its ignition temperature (given evacuation)
*
1.2.2.2.1.2.1.2.1
spark or flame
1.2.2.2.1.2.1.2.2
heat (not spark or flame)
p. 14
p. 15


1.2.2.2.1.2.1.2.1
spark or flame raises explosive mixture of methane and/or airborne coal dust in the intake gate road of a working panel to its ignition temperature
AND
1.2.2.2.1.2.1.2.1.1
spark or flame reaches location of mixture
1.2.2.2.1.2.1.2.1.2
mixture is raised to its ignition temperature by this spark/flame *
OR
1.2.2.2.1.2.1.2.1.1.1
cutting or drilling
1.2.2.2.1.2.1.2.1.1.2
shooting
1.2.2.2.1.2.1.2.1.1.3
electrical equipment
AND
AND
AND
1.2.2.2.1.2.1.2.1.1.1.1
performed in vicinity *
1.2.2.2.1.2.1.2.1.1.2.1
performed in vicinity *
1.2.2.2.1.2.1.2.1.1.3.1
operating in vicinity *
1.2.2.2.1.2.1.2.1.1.1.2
causes spark or flame *
1.2.2.2.1.2.1.2.1.1.2.2
causes spark or flame *
1.2.2.2.1.2.1.2.1.1.3.2
causes spark or flame *
1.2.2.2.1.2.1.2.1.1.1.3
comes in contact with mixture *
1.2.2.2.1.2.1.2.1.1.2.3
comes in contact with mixture *
1.2.2.2.1.2.1.2.1.1.3.3
comes in contact with mixture *
1.2.2.2.1.2.1.2.1.1.4
combustion equipment
1.2.2.2.1.2.1.2.1.1.5
mechanical equipment
1.2.2.2.1.2.1.2.1.1.6
contraband or other
AND
AND
AND
1.2.2.2.1.2.1.2.1.1.4.1
operating in vicinity *
1.2.2.2.1.2.1.2.1.1.5.1
operating in vicinity *
1.2.2.2.1.2.1.2.1.1.6.1
occurs in vicinity *
1.2.2.2.1.2.1.2.1.1.4.2
causes spark or flame *
1.2.2.2.1.2.1.2.1.1.5.2
causes spark or flame *
1.2.2.2.1.2.1.2.1.1.6.2
causes spark or flame *
1.2.2.2.1.2.1.2.1.1.4.3
comes in contact with mixture *
1.2.2.2.1.2.1.2.1.1.5.3
comes in contact with mixture *
1.2.2.2.1.2.1.2.1.1.6.3
comes in contact with mixture *


1.2.2.2.1.2.1.2.2
heat (without spark or flame) raises explosive mixture of methane and/or airborne coal dust in the intake gate road of a working panel to its ignition temp.
AND
1.2.2.2.1.2.1.2.2.1
sufficient heat energy reaches mixture location
1.2.2.2.1.2.1.2.2.2
mixture is raised to its ignition temperature by this heat *
OR
1.2.2.2.1.2.1.2.2.1.1
cutting or drilling
1.2.2.2.1.2.1.2.2.1.2
shooting
1.2.2.2.1.2.1.2.2.1.3
electrical equipment
AND
AND
AND
1.2.2.2.1.2.1.2.2.1.1.1
performed in vicinity *
1.2.2.2.1.2.1.2.2.1.2.1
performed in vicinity *
1.2.2.2.1.2.1.2.2.1.3.1
operating in vicinity *
1.2.2.2.1.2.1.2.2.1.1.2
produces excess heat *
1.2.2.2.1.2.1.2.2.1.2.2
produces excess heat *
1.2.2.2.1.2.1.2.2.1.3.2
produces excess heat *
1.2.2.2.1.2.1.2.2.1.1.3
enough to ignite mixture *
1.2.2.2.1.2.1.2.2.1.2.3
enough to ignite mixture *
1.2.2.2.1.2.1.2.2.1.3.3
enough to ignite mixture *
1.2.2.2.1.2.1.2.2.1.1.4
reaches mixture location *
1.2.2.2.1.2.1.2.2.1.2.4
reaches mixture location *
1.2.2.2.1.2.1.2.2.1.3.4
reaches mixture location *
1.2.2.2.1.2.1.2.2.1.4
combustion equipment
1.2.2.2.1.2.1.2.2.1.5
mechanical equipment
1.2.2.2.1.2.1.2.2.1.6
contraband or other
AND
AND
AND
1.2.2.2.1.2.1.2.2.1.4.1
operating in vicinity *
1.2.2.2.1.2.1.2.2.1.5.1
operating in vicinity *
1.2.2.2.1.2.1.2.2.1.6.1
occurs in vicinity *
1.2.2.2.1.2.1.2.2.1.4.2
causes excess heat *
1.2.2.2.1.2.1.2.2.1.5.2
causes excess heat *
1.2.2.2.1.2.1.2.2.1.6.2
causes excess heat *
1.2.2.2.1.2.1.2.2.1.4.3
enough to ignite mixture *
1.2.2.2.1.2.1.2.2.1.5.3
enough to ignite mixture *
1.2.2.2.1.2.1.2.2.1.6.3
enough to ignite mixture *
1.2.2.2.1.2.1.2.2.1.4.4
reaches mixture location *
1.2.2.2.1.2.1.2.2.1.5.4
reaches mixture location *
1.2.2.2.1.2.1.2.2.1.6.4
reaches mixture location *


1.2.2.2.2
loose coal or accumulated coal dust in the intake gate road of a working panel is raised to its ignition temperature
AND
1.2.2.2.2.1
loose coal or accumulated coal dust is present in the area *
1.2.2.2.2.2
coal is raised to its ignition temperature
OR
1.2.2.2.2.2.1
spark or flame
1.2.2.2.2.2.2
heat (not spark or flame)
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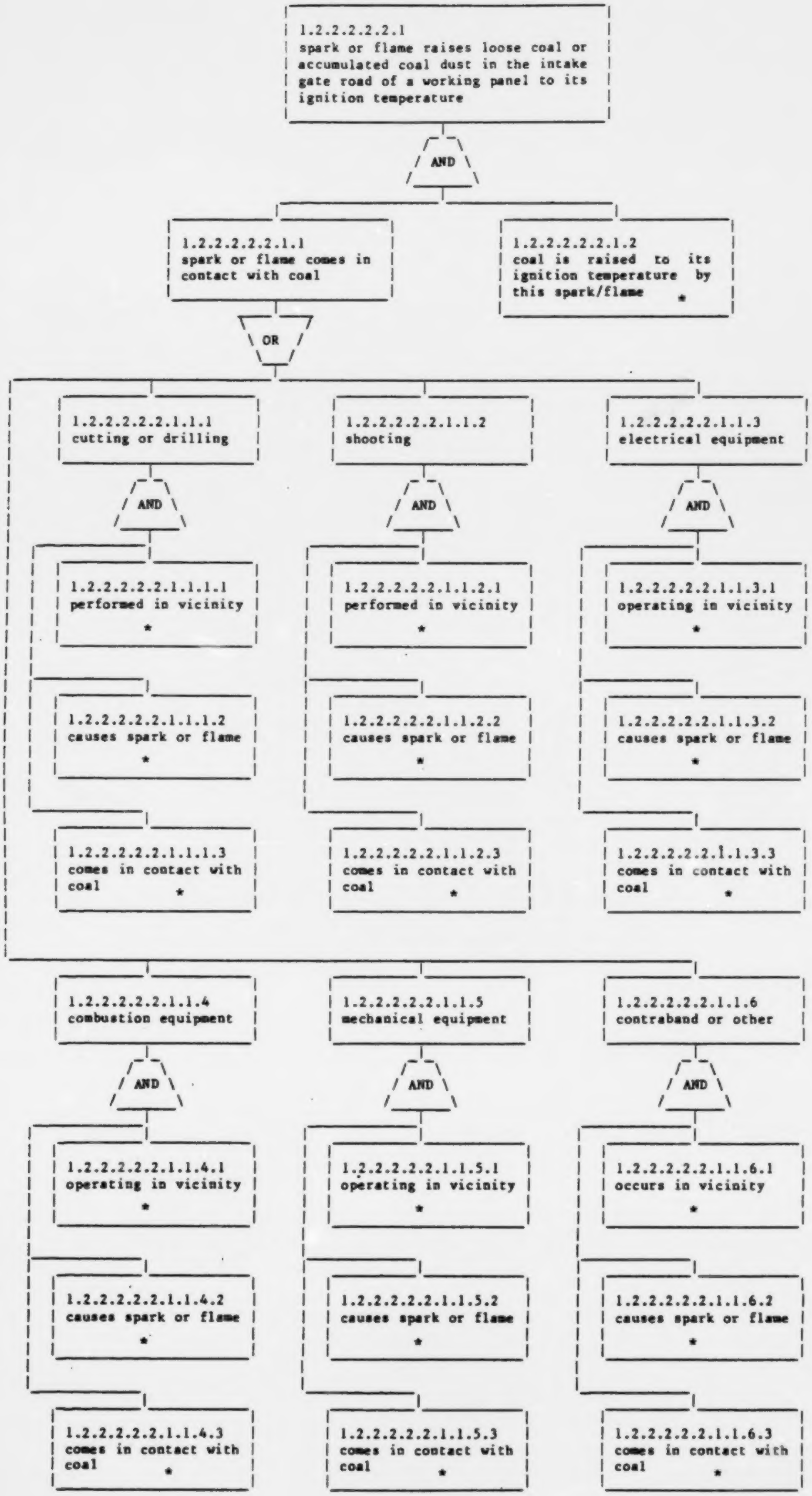
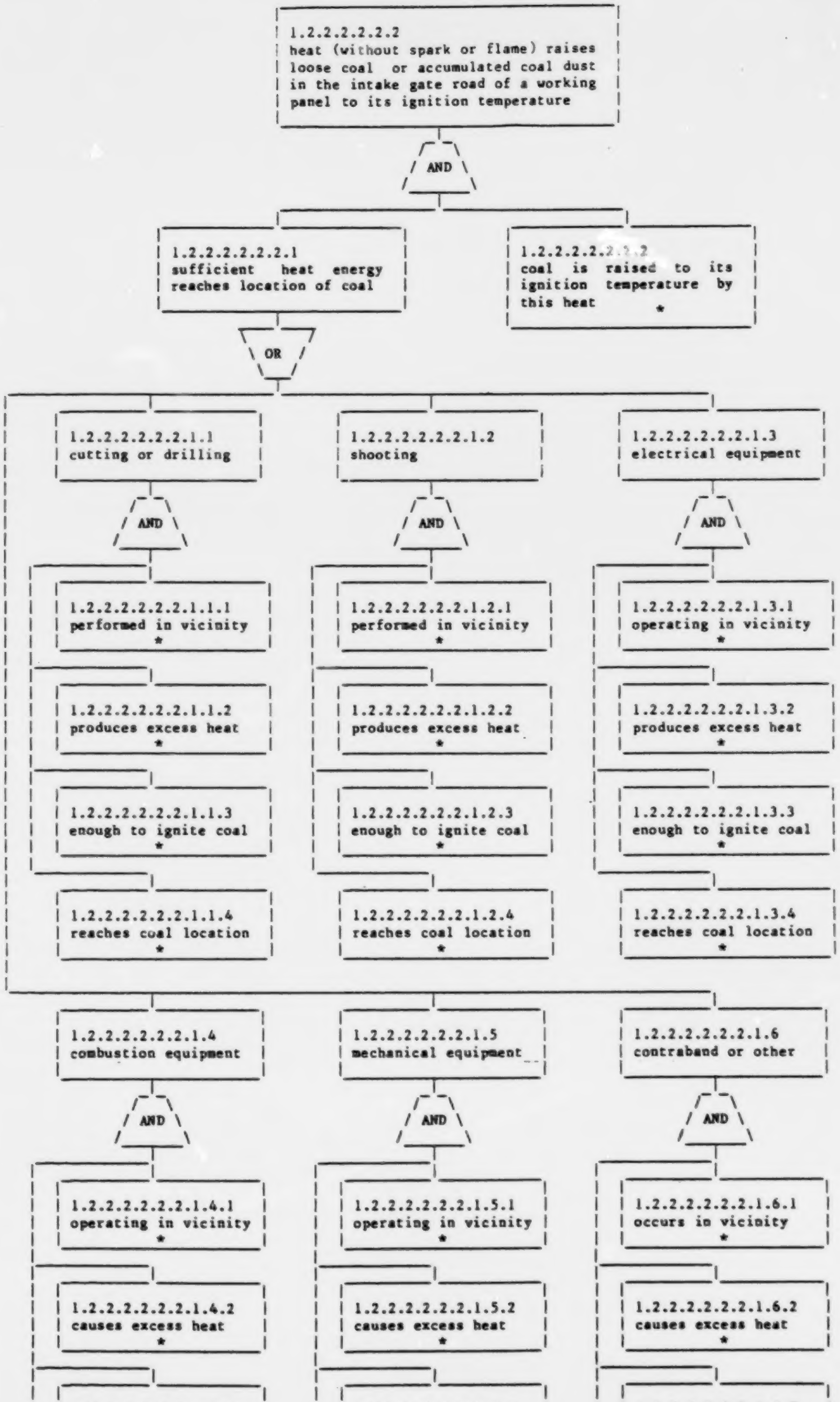
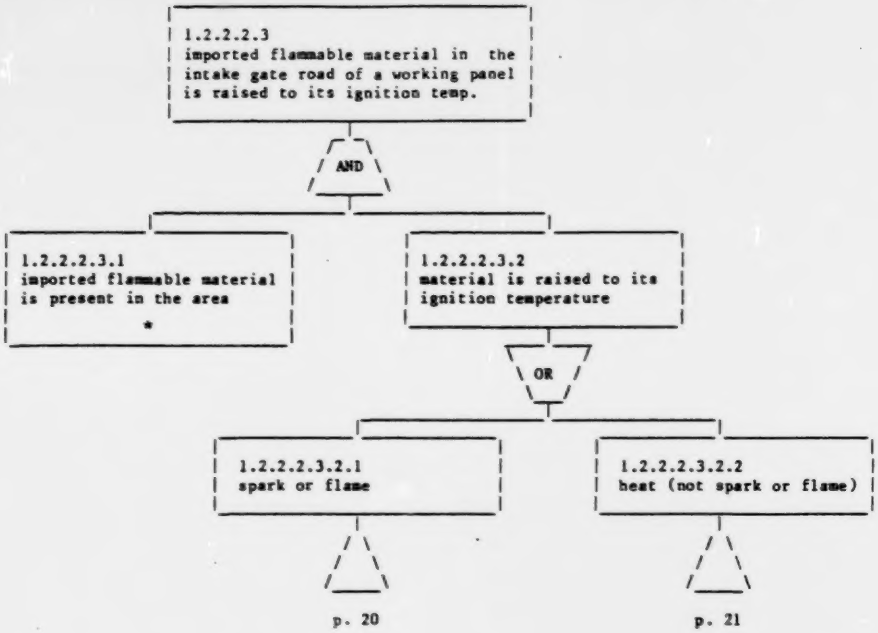
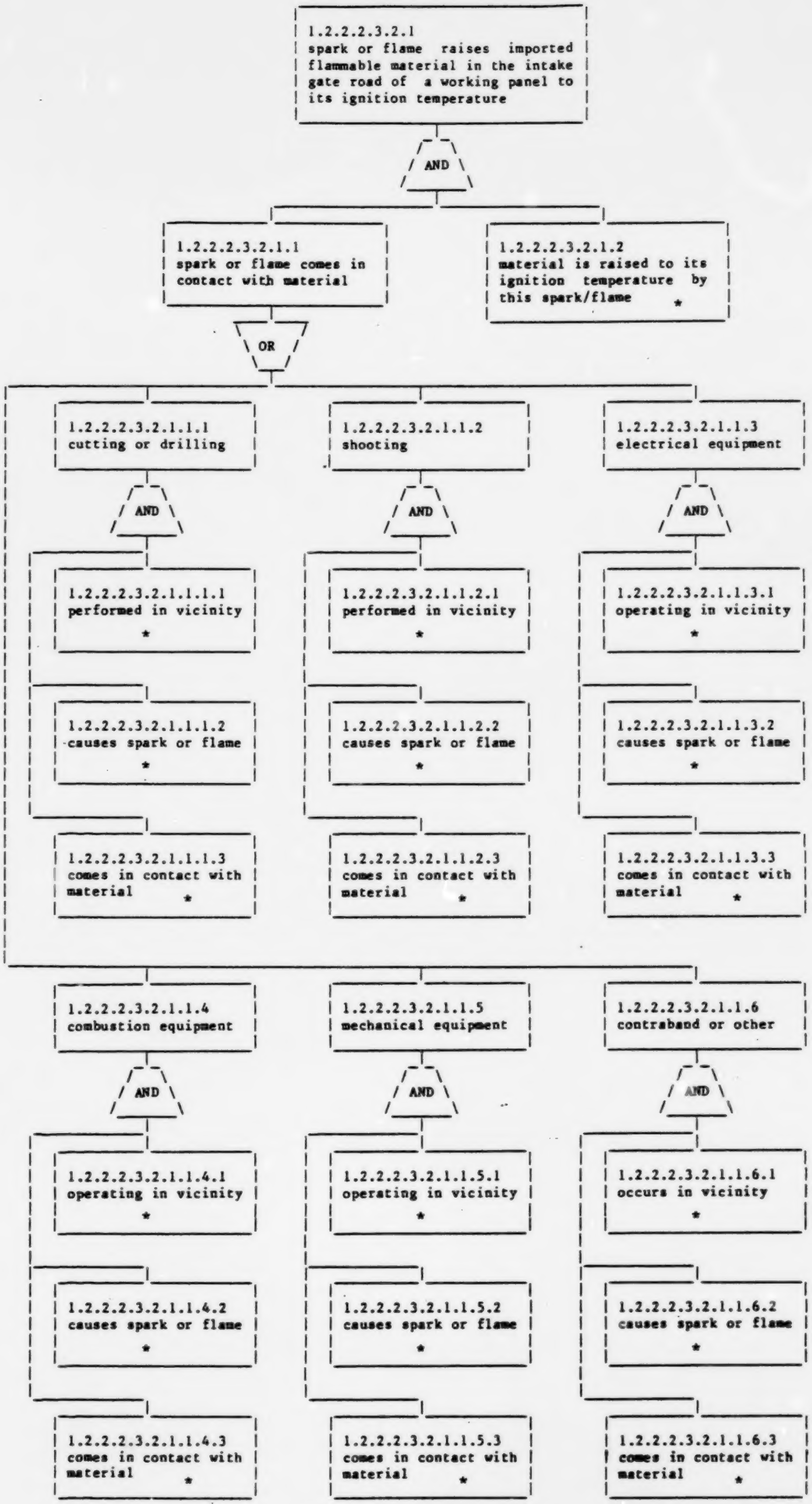
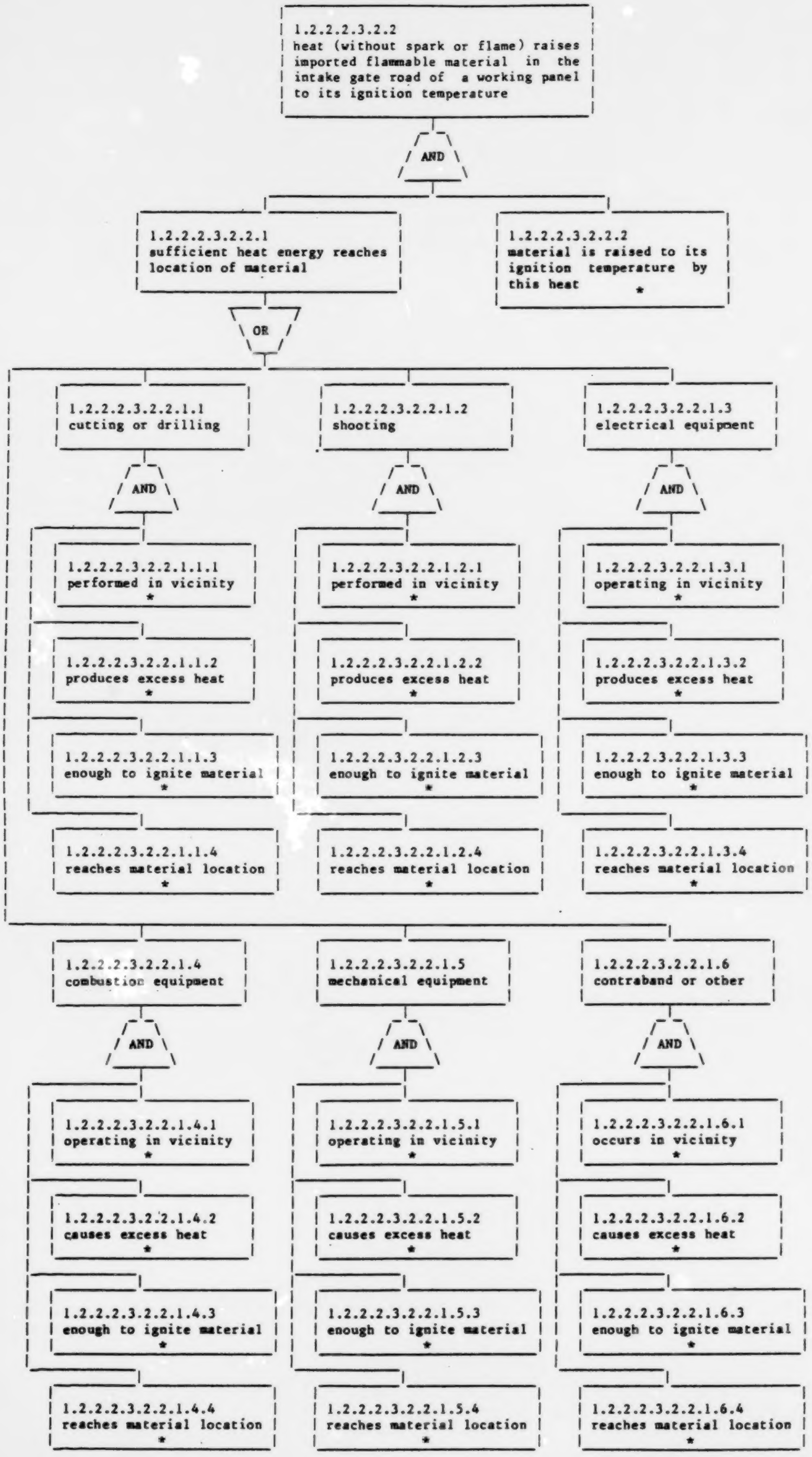
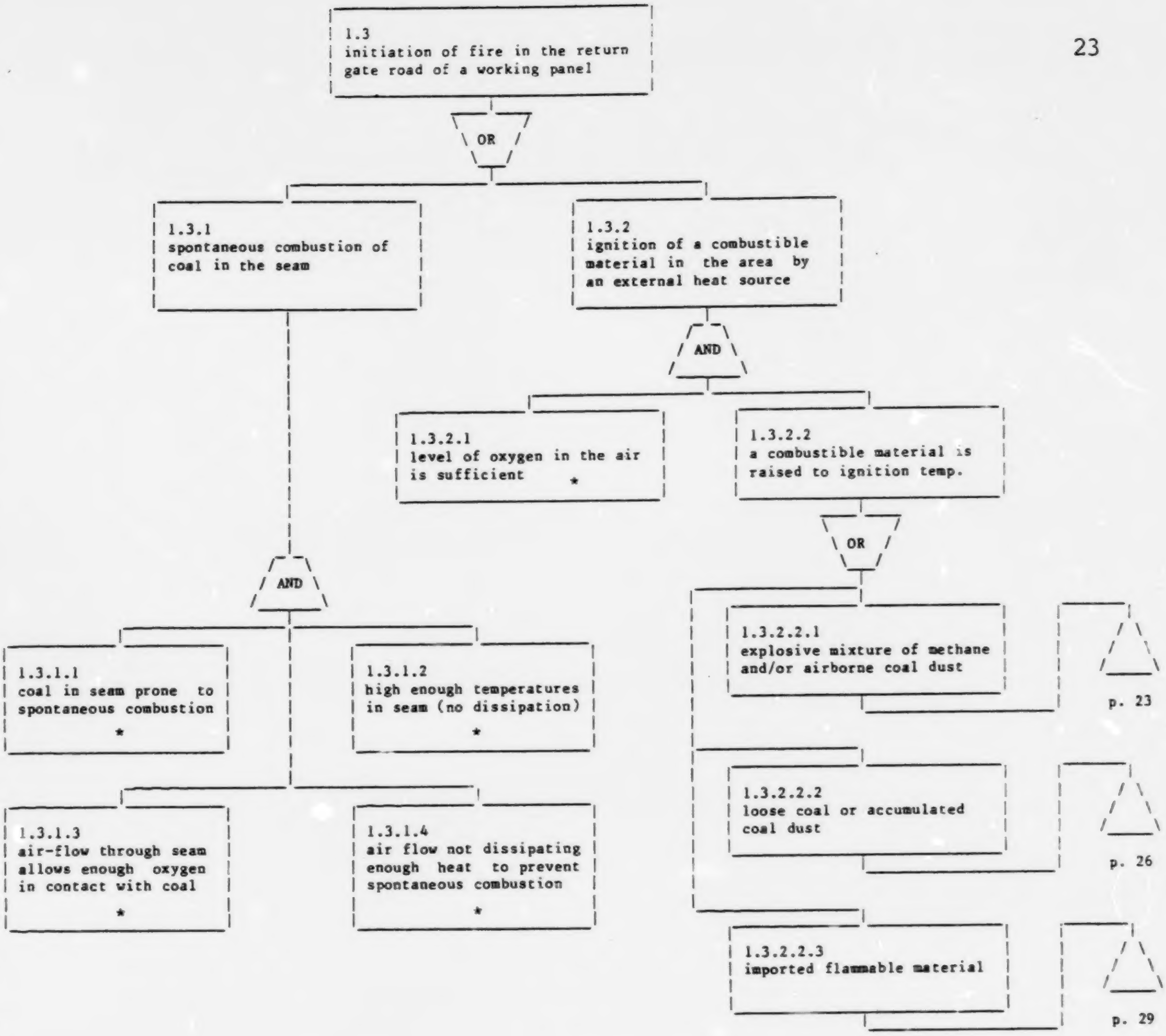

1.2.2.2.2.2.1
spark or flame raises loose coal or accumulated coal dust in the intake gate road of a working panel to its ignition temperature
AND
1.2.2.2.2.2.1.1
spark or flame comes in contact with coal
1.2.2.2.2.2.1.2
coal is raised to its ignition temperature by this spark/flame *
OR
1.2.2.2.2.2.1.1.1
cutting or drilling
1.2.2.2.2.2.1.1.2
shooting
1.2.2.2.2.2.1.1.3
electrical equipment
AND
AND
AND
1.2.2.2.2.2.1.1.1.1
performed in vicinity *
1.2.2.2.2.2.1.1.2.1
performed in vicinity *
1.2.2.2.2.2.1.1.3.1
operating in vicinity *
1.2.2.2.2.2.1.1.1.2
causes spark or flame *
1.2.2.2.2.2.1.1.2.2
causes spark or flame *
1.2.2.2.2.2.1.1.3.2
causes spark or flame *
1.2.2.2.2.2.1.1.1.3
comes in contact with coal *
1.2.2.2.2.2.1.1.2.3
comes in contact with coal *
1.2.2.2.2.2.1.1.3.3
comes in contact with coal *
1.2.2.2.2.2.1.1.4
combustion equipment
1.2.2.2.2.2.1.1.5
mechanical equipment
1.2.2.2.2.2.1.1.6
contraband or other
AND
AND
AND
1.2.2.2.2.2.1.1.4.1
operating in vicinity *
1.2.2.2.2.2.1.1.5.1
operating in vicinity *
1.2.2.2.2.2.1.1.6.1
occurs in vicinity *
1.2.2.2.2.2.1.1.4.2
causes spark or flame *
1.2.2.2.2.2.1.1.5.2
causes spark or flame *
1.2.2.2.2.2.1.1.6.2
causes spark or flame *
1.2.2.2.2.2.1.1.4.3
comes in contact with coal *
1.2.2.2.2.2.1.1.5.3
comes in contact with coal *
1.2.2.2.2.2.1.1.6.3
comes in contact with coal *

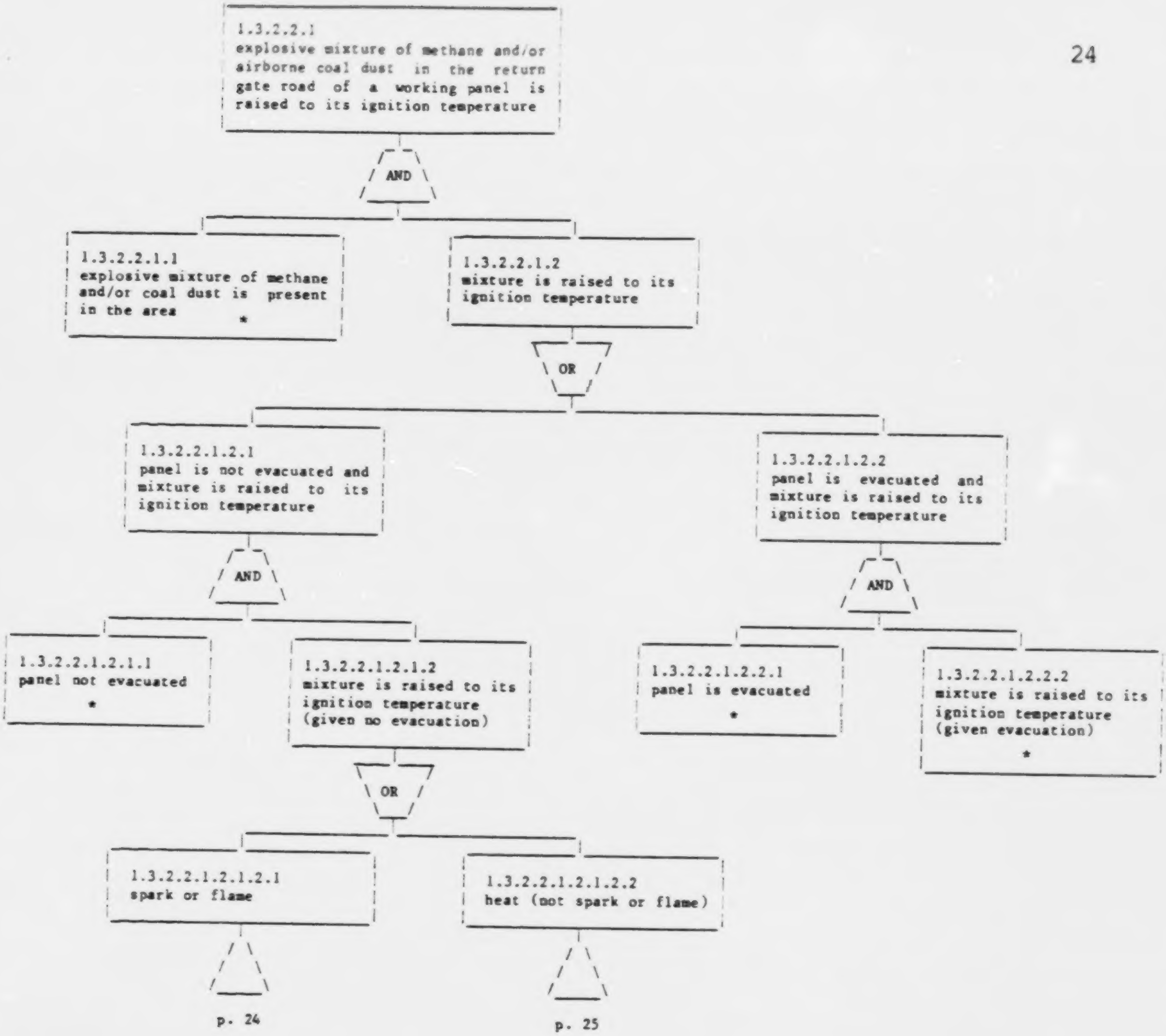

1.2.2.2.2.2.2 heat (without spark or flame) raises loose coal or accumulated coal dust in the intake gate road of a working panel to its ignition temperature
AND
1.2.2.2.2.2.2.1 sufficient heat energy reaches location of coal
1.2.2.2.2.2.2.2 coal is raised to its ignition temperature by this heat *
OR
1.2.2.2.2.2.2.1.1 cutting or drilling
AND
1.2.2.2.2.2.2.1.1.1 performed in vicinity *
1.2.2.2.2.2.2.1.1.2 produces excess heat *
1.2.2.2.2.2.2.1.1.3 enough to ignite coal *
1.2.2.2.2.2.2.1.1.4 reaches coal location *
1.2.2.2.2.2.2.1.2 shooting
AND
1.2.2.2.2.2.2.1.2.1 performed in vicinity *
1.2.2.2.2.2.2.1.2.2 produces excess heat *
1.2.2.2.2.2.2.1.2.3 enough to ignite coal *
1.2.2.2.2.2.2.1.2.4 reaches coal location *
1.2.2.2.2.2.2.1.3 electrical equipment
AND
1.2.2.2.2.2.2.1.3.1 operating in vicinity *
1.2.2.2.2.2.2.1.3.2 produces excess heat *
1.2.2.2.2.2.2.1.3.3 enough to ignite coal *
1.2.2.2.2.2.2.1.3.4 reaches coal location *
1.2.2.2.2.2.2.1.4 combustion equipment
AND
1.2.2.2.2.2.2.1.4.1 operating in vicinity *
1.2.2.2.2.2.2.1.4.2 causes excess heat *
1.2.2.2.2.2.2.1.4.3 enough to ignite coal *
1.2.2.2.2.2.2.1.4.4 reaches coal location *
1.2.2.2.2.2.2.1.5 mechanical equipment
AND
1.2.2.2.2.2.2.1.5.1 operating in vicinity *
1.2.2.2.2.2.2.1.5.2 causes excess heat *
1.2.2.2.2.2.2.1.5.3 enough to ignite coal *
1.2.2.2.2.2.2.1.5.4 reaches coal location *
1.2.2.2.2.2.2.1.6 contraband or other
AND
1.2.2.2.2.2.2.1.6.1 occurs in vicinity *
1.2.2.2.2.2.2.1.6.2 causes excess heat *
1.2.2.2.2.2.2.1.6.3 enough to ignite coal *
1.2.2.2.2.2.2.1.6.4 reaches coal location *

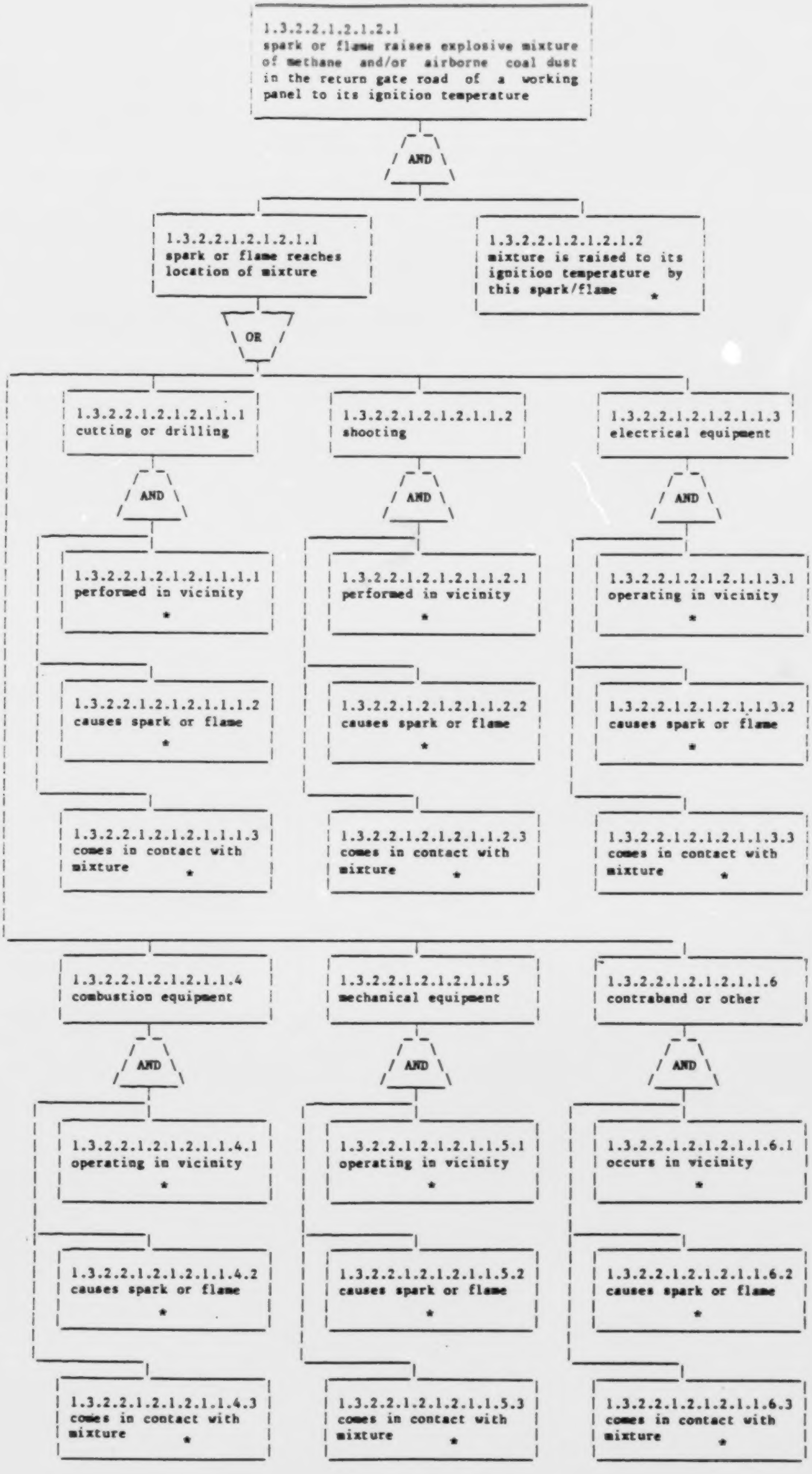

1.2.2.2.3
imported flammable material in the intake gate road of a working panel is raised to its ignition temp.
AND
1.2.2.2.3.1
imported flammable material is present in the area
*
1.2.2.2.3.2
material is raised to its ignition temperature
OR
1.2.2.2.3.2.1
spark or flame
1.2.2.2.3.2.2
heat (not spark or flame)
p. 20
p. 21

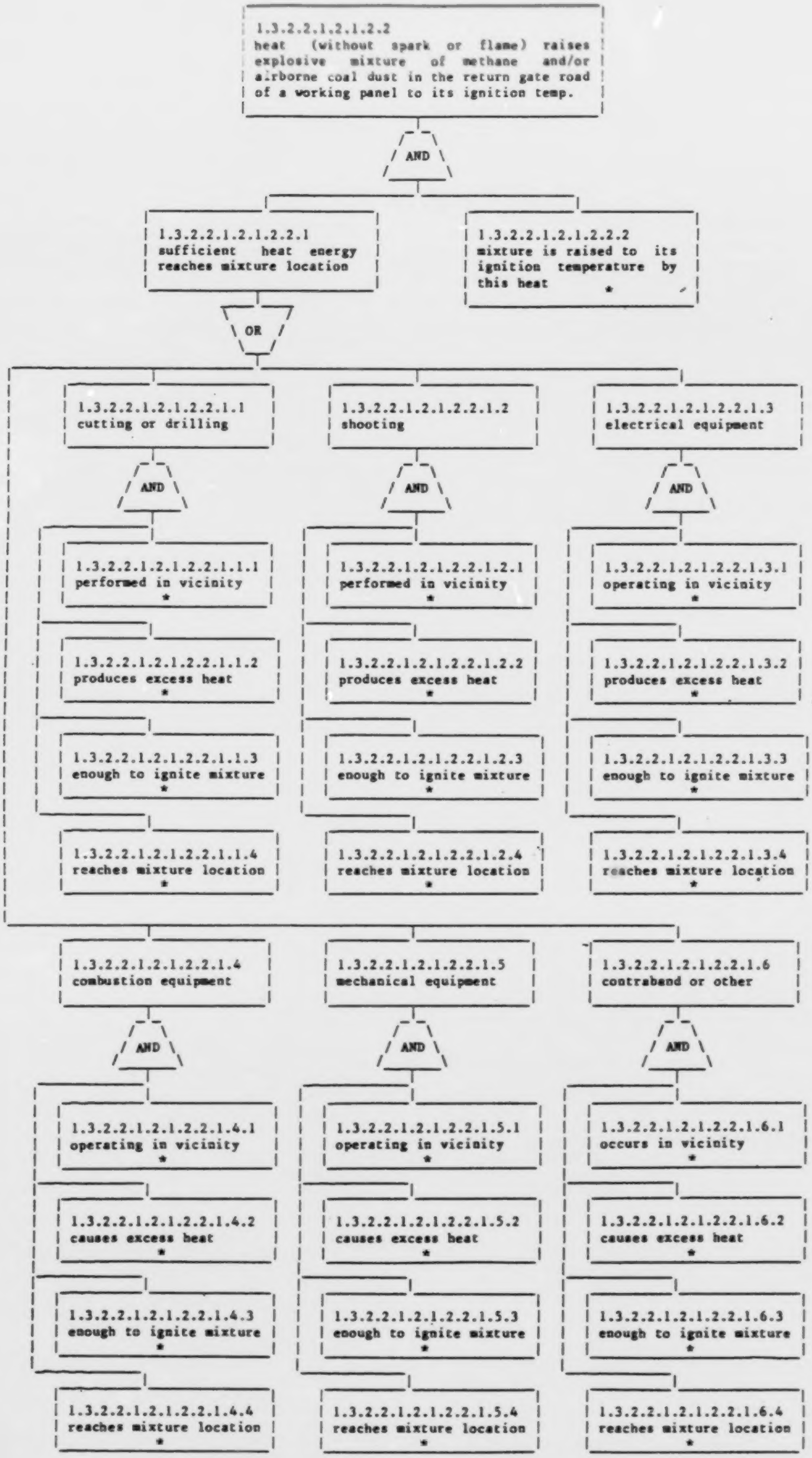

1.2.2.2.3.2.1
spark or flame raises imported flammable material in the intake gate road of a working panel to its ignition temperature
AND
1.2.2.2.3.2.1.1
spark or flame comes in contact with material
1.2.2.2.3.2.1.2
material is raised to its ignition temperature by this spark/flame *
OR
1.2.2.2.3.2.1.1.1
cutting or drilling
1.2.2.2.3.2.1.1.2
shooting
1.2.2.2.3.2.1.1.3
electrical equipment
AND
AND
AND
1.2.2.2.3.2.1.1.1.1
performed in vicinity *
1.2.2.2.3.2.1.1.2.1
performed in vicinity *
1.2.2.2.3.2.1.1.3.1
operating in vicinity *
1.2.2.2.3.2.1.1.1.2
causes spark or flame *
1.2.2.2.3.2.1.1.2.2
causes spark or flame *
1.2.2.2.3.2.1.1.3.2
causes spark or flame *
1.2.2.2.3.2.1.1.1.3
comes in contact with material *
1.2.2.2.3.2.1.1.2.3
comes in contact with material *
1.2.2.2.3.2.1.1.3.3
comes in contact with material *
1.2.2.2.3.2.1.1.4
combustion equipment
1.2.2.2.3.2.1.1.5
mechanical equipment
1.2.2.2.3.2.1.1.6
contraband or other
AND
AND
AND
1.2.2.2.3.2.1.1.4.1
operating in vicinity *
1.2.2.2.3.2.1.1.5.1
operating in vicinity *
1.2.2.2.3.2.1.1.6.1
occurs in vicinity *
1.2.2.2.3.2.1.1.4.2
causes spark or flame *
1.2.2.2.3.2.1.1.5.2
causes spark or flame *
1.2.2.2.3.2.1.1.6.2
causes spark or flame *
1.2.2.2.3.2.1.1.4.3
comes in contact with material *
1.2.2.2.3.2.1.1.5.3
comes in contact with material *
1.2.2.2.3.2.1.1.6.3
comes in contact with material *

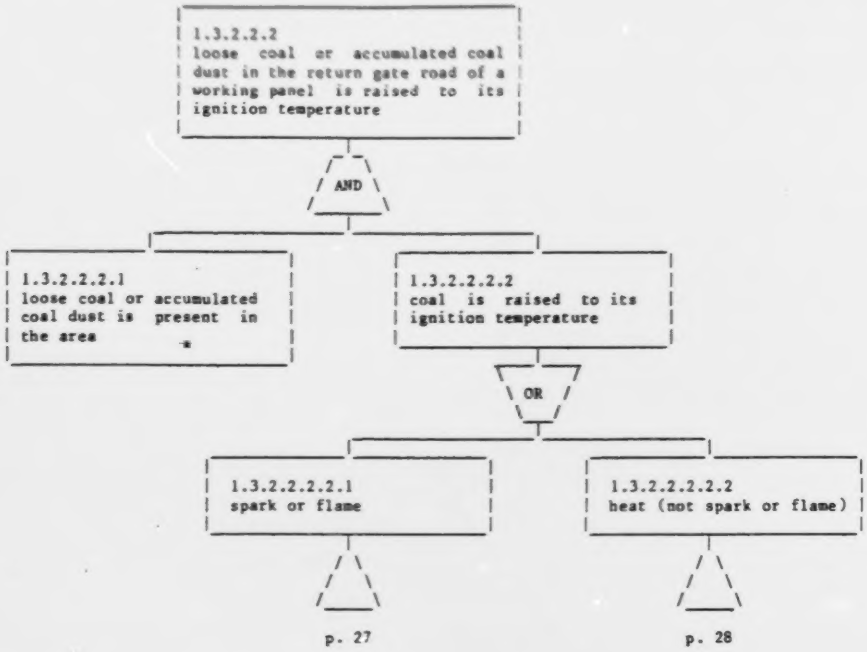

1.2.2.2.3.2.2
heat (without spark or flame) raises imported flammable material in the intake gate road of a working panel to its ignition temperature
AND
1.2.2.2.3.2.2.1
sufficient heat energy reaches location of material
1.2.2.2.3.2.2.2
material is raised to its ignition temperature by this heat *
OR
1.2.2.2.3.2.2.1.1
cutting or drilling
1.2.2.2.3.2.2.1.2
shooting
1.2.2.2.3.2.2.1.3
electrical equipment
AND
AND
AND
1.2.2.2.3.2.2.1.1.1
performed in vicinity *
1.2.2.2.3.2.2.1.2.1
performed in vicinity *
1.2.2.2.3.2.2.1.3.1
operating in vicinity *
1.2.2.2.3.2.2.1.1.2
produces excess heat *
1.2.2.2.3.2.2.1.2.2
produces excess heat *
1.2.2.2.3.2.2.1.3.2
produces excess heat *
1.2.2.2.3.2.2.1.1.3
enough to ignite material *
1.2.2.2.3.2.2.1.2.3
enough to ignite material *
1.2.2.2.3.2.2.1.3.3
enough to ignite material *
1.2.2.2.3.2.2.1.1.4
reaches material location *
1.2.2.2.3.2.2.1.2.4
reaches material location *
1.2.2.2.3.2.2.1.3.4
reaches material location *
1.2.2.2.3.2.2.1.4
combustion equipment
1.2.2.2.3.2.2.1.5
mechanical equipment
1.2.2.2.3.2.2.1.6
contraband or other
AND
AND
AND
1.2.2.2.3.2.2.1.4.1
operating in vicinity *
1.2.2.2.3.2.2.1.5.1
operating in vicinity *
1.2.2.2.3.2.2.1.6.1
occurs in vicinity *
1.2.2.2.3.2.2.1.4.2
causes excess heat *
1.2.2.2.3.2.2.1.5.2
causes excess heat *
1.2.2.2.3.2.2.1.6.2
causes excess heat *
1.2.2.2.3.2.2.1.4.3
enough to ignite material *
1.2.2.2.3.2.2.1.5.3
enough to ignite material *
1.2.2.2.3.2.2.1.6.3
enough to ignite material *
1.2.2.2.3.2.2.1.4.4
reaches material location *
1.2.2.2.3.2.2.1.5.4
reaches material location *
1.2.2.2.3.2.2.1.6.4
reaches material location *


1.3
initiation of fire in the return gate road of a working panel
OR
1.3.1
spontaneous combustion of coal in the seam
1.3.2
ignition of a combustible material in the area by an external heat source
AND
1.3.2.1
level of oxygen in the air is sufficient *
1.3.2.2
a combustible material is raised to ignition temp.
OR
AND
1.3.1.1
coal in seam prone to spontaneous combustion *
1.3.1.2
high enough temperatures in seam (no dissipation) *
1.3.2.2.1
explosive mixture of methane and/or airborne coal dust
p. 23
1.3.2.2.2
loose coal or accumulated coal dust
p. 26
1.3.1.3
air-flow through seam allows enough oxygen in contact with coal *
1.3.1.4
air flow not dissipating enough heat to prevent spontaneous combustion *
1.3.2.2.3
imported flammable material
p. 29


1.3.2.2.1
explosive mixture of methane and/or airborne coal dust in the return gate road of a working panel is raised to its ignition temperature
AND
1.3.2.2.1.1
explosive mixture of methane and/or coal dust is present in the area
*
1.3.2.2.1.2
mixture is raised to its ignition temperature
OR
1.3.2.2.1.2.1
panel is not evacuated and mixture is raised to its ignition temperature
AND
1.3.2.2.1.2.1.1
panel not evacuated
*
1.3.2.2.1.2.1.2
mixture is raised to its ignition temperature (given no evacuation)
OR
1.3.2.2.1.2.1.2.1
spark or flame
p. 24
1.3.2.2.1.2.1.2.2
heat (not spark or flame)
p. 25
1.3.2.2.1.2.2
panel is evacuated and mixture is raised to its ignition temperature
AND
1.3.2.2.1.2.2.1
panel is evacuated
*
1.3.2.2.1.2.2.2
mixture is raised to its ignition temperature (given evacuation)
*


1.3.2.2.1.2.1.2.1
spark or flame raises explosive mixture of methane and/or airborne coal dust in the return gate road of a working panel to its ignition temperature
AND
1.3.2.2.1.2.1.2.1.1
spark or flame reaches location of mixture
1.3.2.2.1.2.1.2.1.2
mixture is raised to its ignition temperature by this spark/flame *
OR
1.3.2.2.1.2.1.2.1.1.1
cutting or drilling
1.3.2.2.1.2.1.2.1.1.2
shooting
1.3.2.2.1.2.1.2.1.1.3
electrical equipment
AND
AND
AND
1.3.2.2.1.2.1.2.1.1.1.1
performed in vicinity *
1.3.2.2.1.2.1.2.1.1.2.1
performed in vicinity *
1.3.2.2.1.2.1.2.1.1.3.1
operating in vicinity *
1.3.2.2.1.2.1.2.1.1.1.2
causes spark or flame *
1.3.2.2.1.2.1.2.1.1.2.2
causes spark or flame *
1.3.2.2.1.2.1.2.1.1.3.2
causes spark or flame *
1.3.2.2.1.2.1.2.1.1.1.3
comes in contact with mixture *
1.3.2.2.1.2.1.2.1.1.2.3
comes in contact with mixture *
1.3.2.2.1.2.1.2.1.1.3.3
comes in contact with mixture *
1.3.2.2.1.2.1.2.1.1.4
combustion equipment
1.3.2.2.1.2.1.2.1.1.5
mechanical equipment
1.3.2.2.1.2.1.2.1.1.6
contraband or other
AND
AND
AND
1.3.2.2.1.2.1.2.1.1.4.1
operating in vicinity *
1.3.2.2.1.2.1.2.1.1.5.1
operating in vicinity *
1.3.2.2.1.2.1.2.1.1.6.1
occurs in vicinity *
1.3.2.2.1.2.1.2.1.1.4.2
causes spark or flame *
1.3.2.2.1.2.1.2.1.1.5.2
causes spark or flame *
1.3.2.2.1.2.1.2.1.1.6.2
causes spark or flame *
1.3.2.2.1.2.1.2.1.1.4.3
comes in contact with mixture *
1.3.2.2.1.2.1.2.1.1.5.3
comes in contact with mixture *
1.3.2.2.1.2.1.2.1.1.6.3
comes in contact with mixture *


1.3.2.2.1.2.1.2.2
heat (without spark or flame) raises explosive mixture of methane and/or airborne coal dust in the return gate road of a working panel to its ignition temp.
AND
1.3.2.2.1.2.1.2.2.1
sufficient heat energy reaches mixture location
1.3.2.2.1.2.1.2.2.2
mixture is raised to its ignition temperature by this heat
*
OR
1.3.2.2.1.2.1.2.2.1.1
cutting or drilling
1.3.2.2.1.2.1.2.2.1.2
shooting
1.3.2.2.1.2.1.2.2.1.3
electrical equipment
AND
AND
AND
1.3.2.2.1.2.1.2.2.1.1.1
performed in vicinity
*
1.3.2.2.1.2.1.2.2.1.1.2
produces excess heat
*
1.3.2.2.1.2.1.2.2.1.1.3
enough to ignite mixture
*
1.3.2.2.1.2.1.2.2.1.1.4
reaches mixture location
*
1.3.2.2.1.2.1.2.2.1.2.1
performed in vicinity
*
1.3.2.2.1.2.1.2.2.1.2.2
produces excess heat
*
1.3.2.2.1.2.1.2.2.1.2.3
enough to ignite mixture
*
1.3.2.2.1.2.1.2.2.1.2.4
reaches mixture location
*
1.3.2.2.1.2.1.2.2.1.3.1
operating in vicinity
*
1.3.2.2.1.2.1.2.2.1.3.2
produces excess heat
*
1.3.2.2.1.2.1.2.2.1.3.3
enough to ignite mixture
*
1.3.2.2.1.2.1.2.2.1.3.4
reaches mixture location
*
1.3.2.2.1.2.1.2.2.1.4
combustion equipment
1.3.2.2.1.2.1.2.2.1.5
mechanical equipment
1.3.2.2.1.2.1.2.2.1.6
contraband or other
AND
AND
AND
1.3.2.2.1.2.1.2.2.1.4.1
operating in vicinity
*
1.3.2.2.1.2.1.2.2.1.4.2
causes excess heat
*
1.3.2.2.1.2.1.2.2.1.4.3
enough to ignite mixture
*
1.3.2.2.1.2.1.2.2.1.4.4
reaches mixture location
*
1.3.2.2.1.2.1.2.2.1.5.1
operating in vicinity
*
1.3.2.2.1.2.1.2.2.1.5.2
causes excess heat
*
1.3.2.2.1.2.1.2.2.1.5.3
enough to ignite mixture
*
1.3.2.2.1.2.1.2.2.1.5.4
reaches mixture location
*
1.3.2.2.1.2.1.2.2.1.6.1
occurs in vicinity
*
1.3.2.2.1.2.1.2.2.1.6.2
causes excess heat
*
1.3.2.2.1.2.1.2.2.1.6.3
enough to ignite mixture
*
1.3.2.2.1.2.1.2.2.1.6.4
reaches mixture location
*



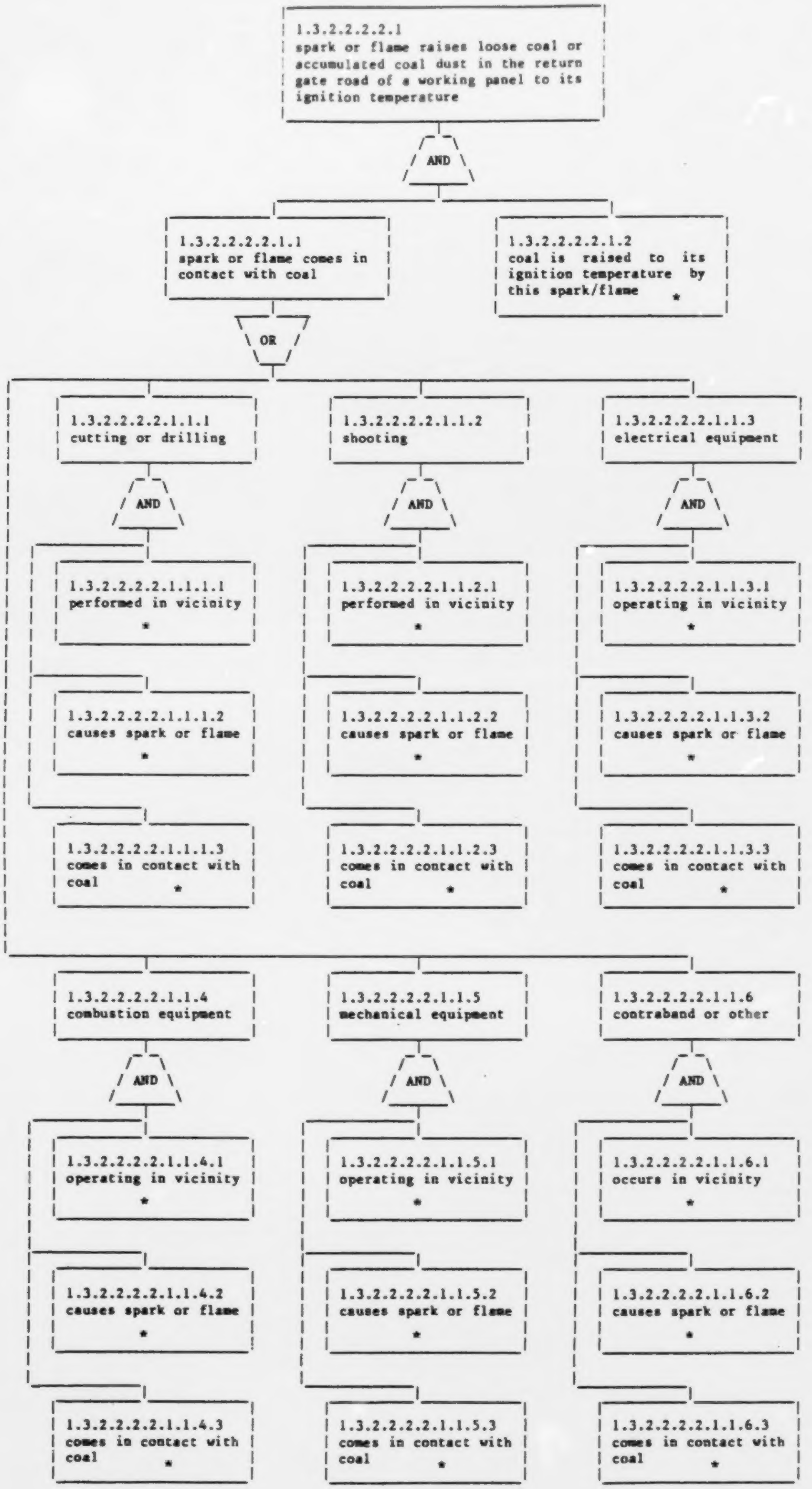
1.3.2.2.2
loose coal or accumulated coal dust in the return gate road of a working panel is raised to its ignition temperature

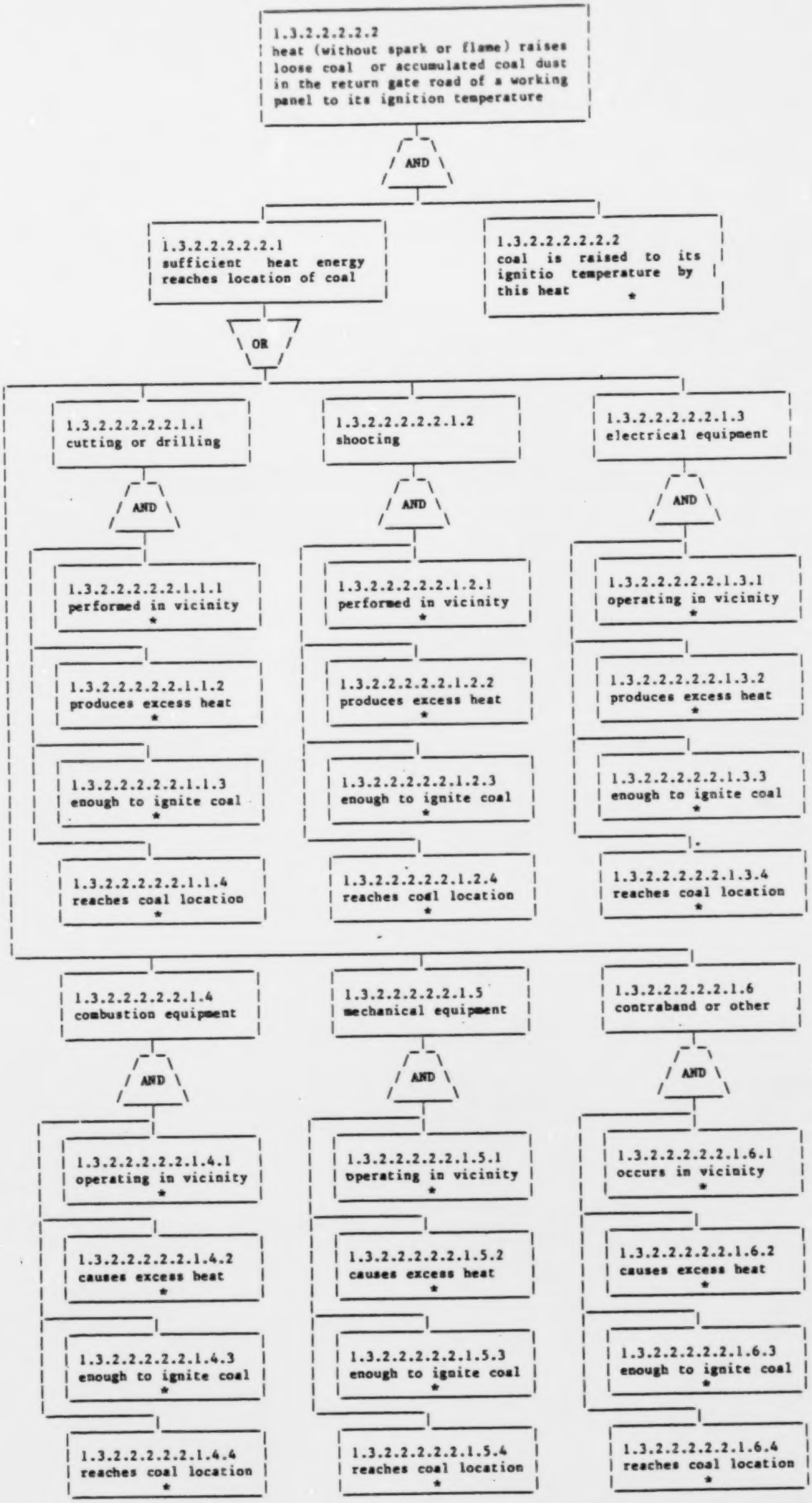
1.3.2.2.2.1
loose coal or accumulated coal dust is present in the area *

1.3.2.2.2.2
coal is raised to its ignition temperature

1.3.2.2.2.2.1
spark or flame

1.3.2.2.2.2.2
heat (not spark or flame)


1.3.2.2.2.2.1 spark or flame raises loose coal or accumulated coal dust in the return gate road of a working panel to its ignition temperature
AND
1.3.2.2.2.2.1.1 spark or flame comes in contact with coal
1.3.2.2.2.2.1.2 coal is raised to its ignition temperature by this spark/flame *
OR
1.3.2.2.2.2.1.1.1 cutting or drilling
1.3.2.2.2.2.1.1.2 shooting
1.3.2.2.2.2.1.1.3 electrical equipment
AND
AND
AND
1.3.2.2.2.2.1.1.1.1 performed in vicinity *
1.3.2.2.2.2.1.1.2.1 performed in vicinity *
1.3.2.2.2.2.1.1.3.1 operating in vicinity *
1.3.2.2.2.2.1.1.1.2 causes spark or flame *
1.3.2.2.2.2.1.1.2.2 causes spark or flame *
1.3.2.2.2.2.1.1.3.2 causes spark or flame *
1.3.2.2.2.2.1.1.1.3 comes in contact with coal *
1.3.2.2.2.2.1.1.2.3 comes in contact with coal *
1.3.2.2.2.2.1.1.3.3 comes in contact with coal *
1.3.2.2.2.2.1.1.4 combustion equipment
1.3.2.2.2.2.1.1.5 mechanical equipment
1.3.2.2.2.2.1.1.6 contraband or other
AND
AND
AND
1.3.2.2.2.2.1.1.4.1 operating in vicinity *
1.3.2.2.2.2.1.1.5.1 operating in vicinity *
1.3.2.2.2.2.1.1.6.1 occurs in vicinity *
1.3.2.2.2.2.1.1.4.2 causes spark or flame *
1.3.2.2.2.2.1.1.5.2 causes spark or flame *
1.3.2.2.2.2.1.1.6.2 causes spark or flame *
1.3.2.2.2.2.1.1.4.3 comes in contact with coal *
1.3.2.2.2.2.1.1.5.3 comes in contact with coal *
1.3.2.2.2.2.1.1.6.3 comes in contact with coal *


1.3.2.2.2.2.2
heat (without spark or flame) raises loose coal or accumulated coal dust in the return gate road of a working panel to its ignition temperature
AND
1.3.2.2.2.2.2.1
sufficient heat energy reaches location of coal
1.3.2.2.2.2.2.2
coal is raised to its ignitio temperature by this heat *
OR
1.3.2.2.2.2.2.1.1
cutting or drilling
AND
1.3.2.2.2.2.2.1.1.1
performed in vicinity *
1.3.2.2.2.2.2.1.1.2
produces excess heat *
1.3.2.2.2.2.2.1.1.3
enough to ignite coal *
1.3.2.2.2.2.2.1.1.4
reaches coal location *
1.3.2.2.2.2.2.1.2
shooting
AND
1.3.2.2.2.2.2.1.2.1
performed in vicinity *
1.3.2.2.2.2.2.1.2.2
produces excess heat *
1.3.2.2.2.2.2.1.2.3
enough to ignite coal *
1.3.2.2.2.2.2.1.2.4
reaches coal location *
1.3.2.2.2.2.2.1.3
electrical equipment
AND
1.3.2.2.2.2.2.1.3.1
operating in vicinity *
1.3.2.2.2.2.2.1.3.2
produces excess heat *
1.3.2.2.2.2.2.1.3.3
enough to ignite coal *
1.3.2.2.2.2.2.1.3.4
reaches coal location *
1.3.2.2.2.2.2.1.4
combustion equipment
AND
1.3.2.2.2.2.2.1.4.1
operating in vicinity *
1.3.2.2.2.2.2.1.4.2
causes excess heat *
1.3.2.2.2.2.2.1.4.3
enough to ignite coal *
1.3.2.2.2.2.2.1.4.4
reaches coal location *
1.3.2.2.2.2.2.1.5
mechanical equipment
AND
1.3.2.2.2.2.2.1.5.1
operating in vicinity *
1.3.2.2.2.2.2.1.5.2
causes excess heat *
1.3.2.2.2.2.2.1.5.3
enough to ignite coal *
1.3.2.2.2.2.2.1.5.4
reaches coal location *
1.3.2.2.2.2.2.1.6
contraband or other
AND
1.3.2.2.2.2.2.1.6.1
occurs in vicinity *
1.3.2.2.2.2.2.1.6.2
causes excess heat *
1.3.2.2.2.2.2.1.6.3
enough to ignite coal *
1.3.2.2.2.2.2.1.6.4
reaches coal location *

```
                        ________________________________________
                       |                                        |
                       | 1.3.2.2.3                              |
                       | imported flammable material in  the   |
                       | return gate road of a working panel    |
                       | is raised to its ignition temp.        |
                       |________________________________________|
                                          |
                                        /‾‾‾\
                                       / AND \
                                      /_______\
                                          |
             _____________________________|____________________________
            |                                                           |
 ___________|______________________                   __________________|__________________
|                                  |                 |                                    |
| 1.3.2.2.3.1                      |                 | 1.3.2.2.3.2                        |
| imported flammable material      |                 | material is raised to its          |
| is present in the area           |                 | ignition tem erature               |
|                *                 |                 |____________________________________|
|__________________________________|                                    |
                                                                  \‾‾‾‾‾‾‾‾‾/
                                                                   \  OR   /
                                                                    \_____/
                                                                       |
                                    ___________________________________|_______________________
                                   |                                                           |
                 __________________|________________                     _______________________|_______________
                |                                   |                   |                                      |
                |  1.3.2.2.3.2.1                    |                   |  1.3.2.2.3.2.2                       |
                |  spark or flame                   |                   |  heat (not spark or flame)           |
                |___________________________________|                   |______________________________________|
                                  |                                                          |
                                 / \                                                        / \
                                /   \                                                      /   \
                               /_____\                                                    /_____\

                                p. 30                                                      p. 31
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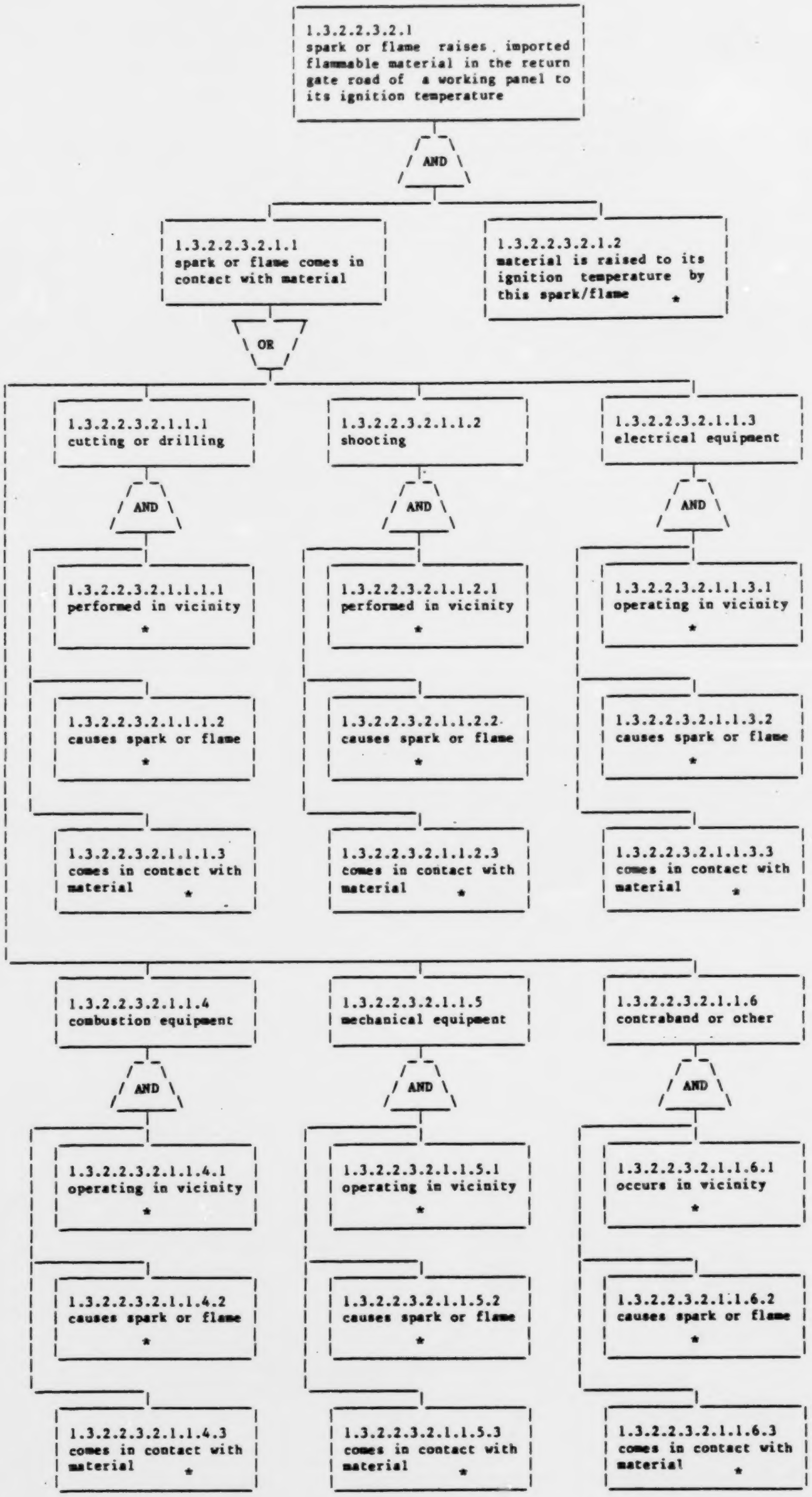
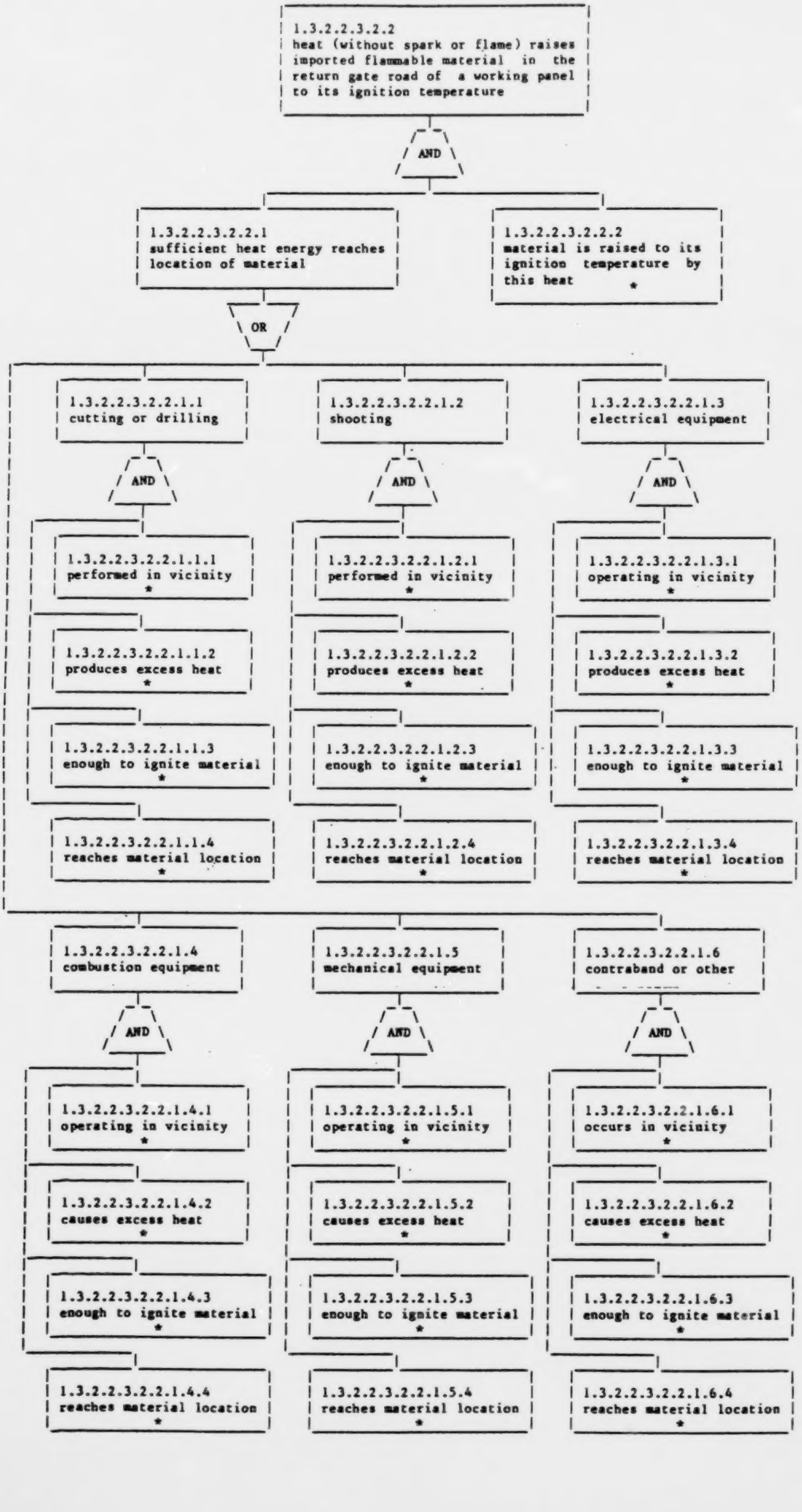
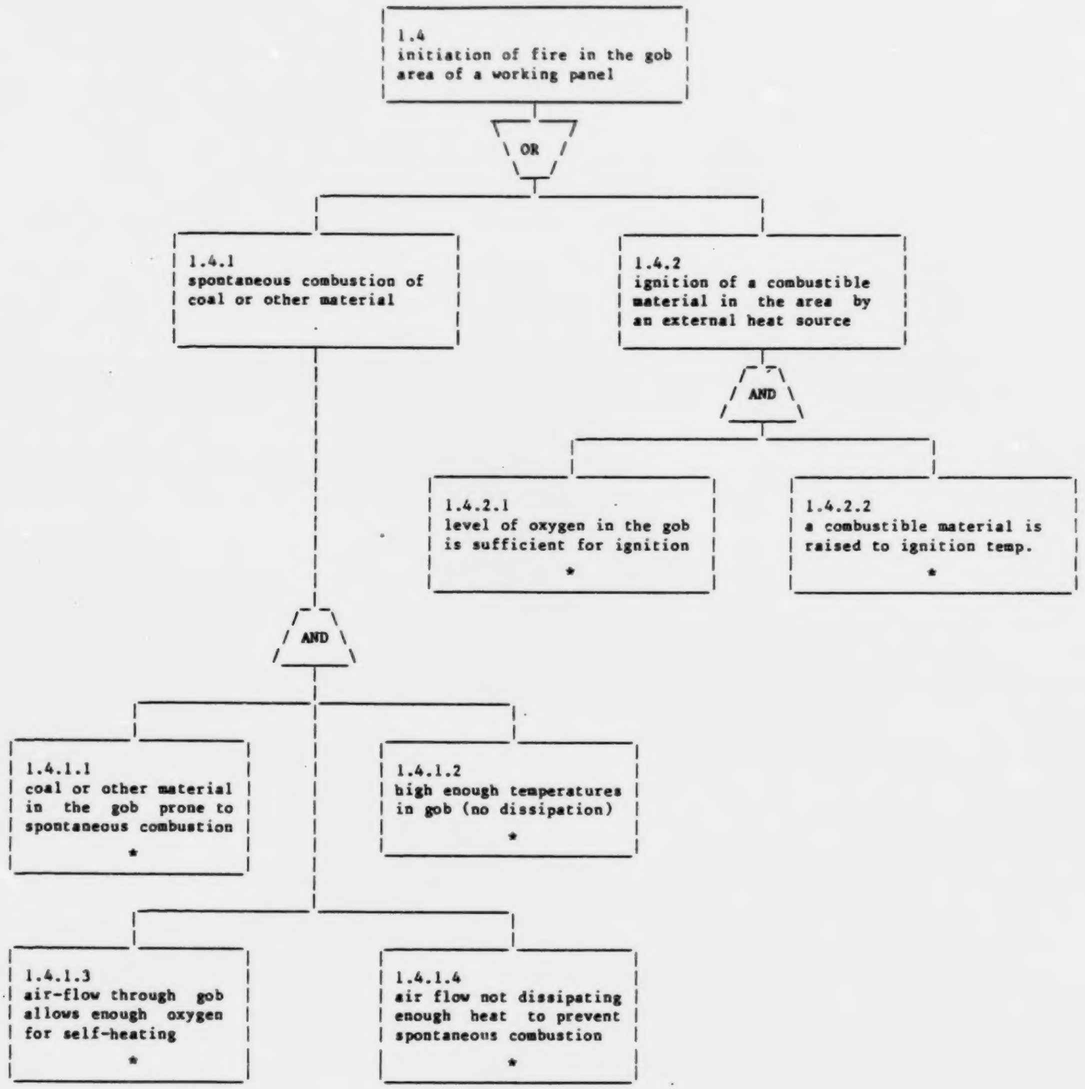
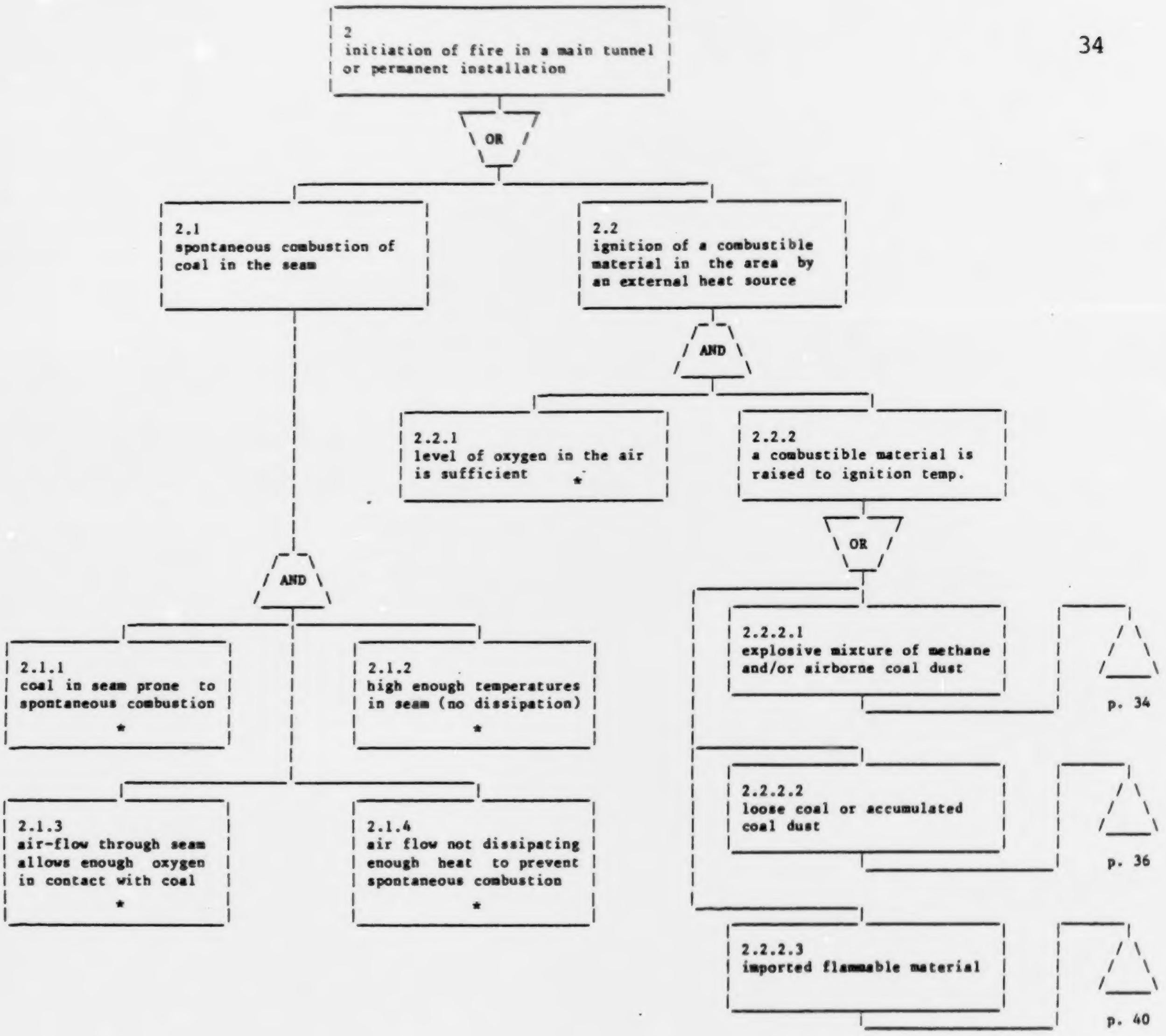
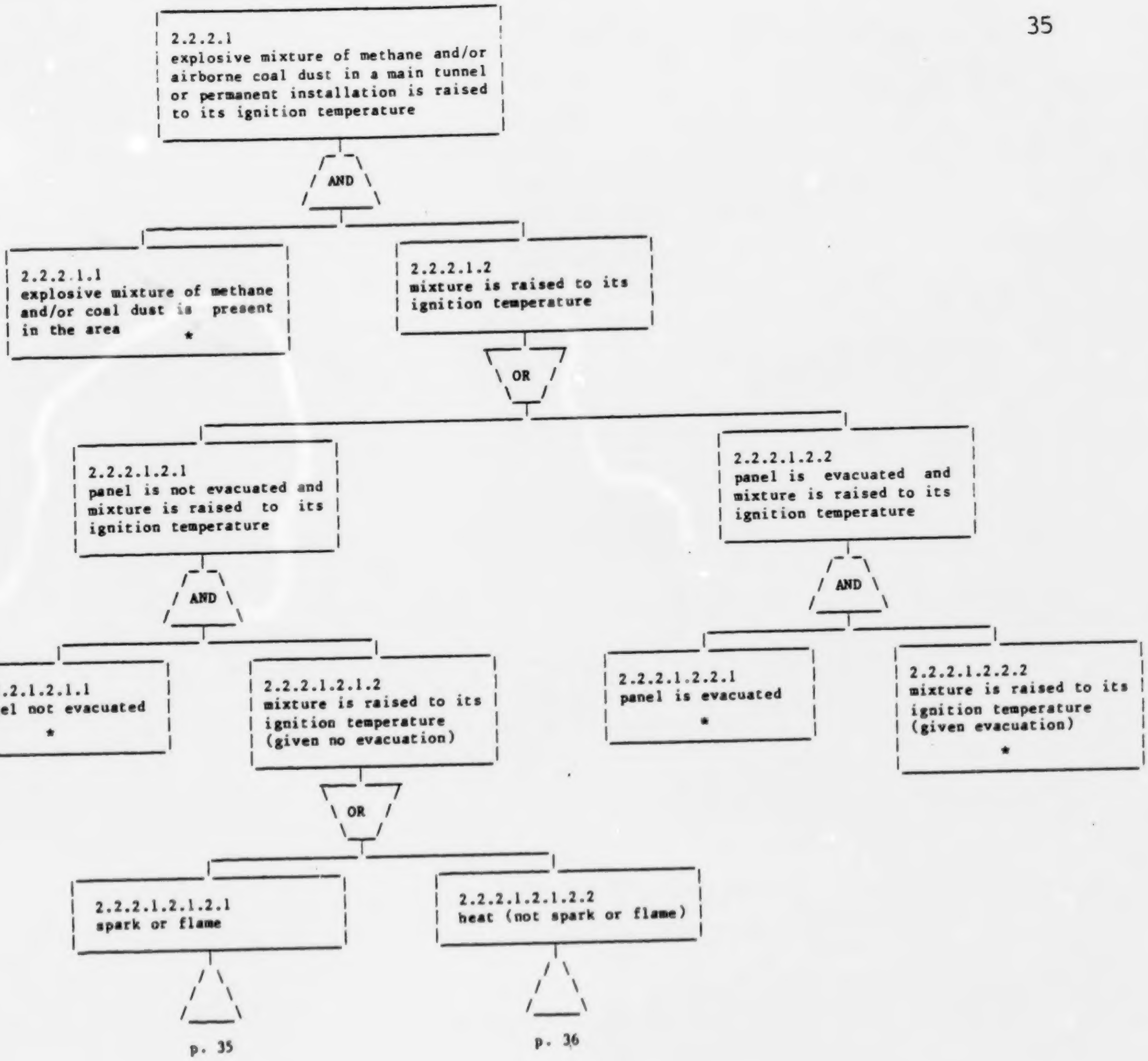
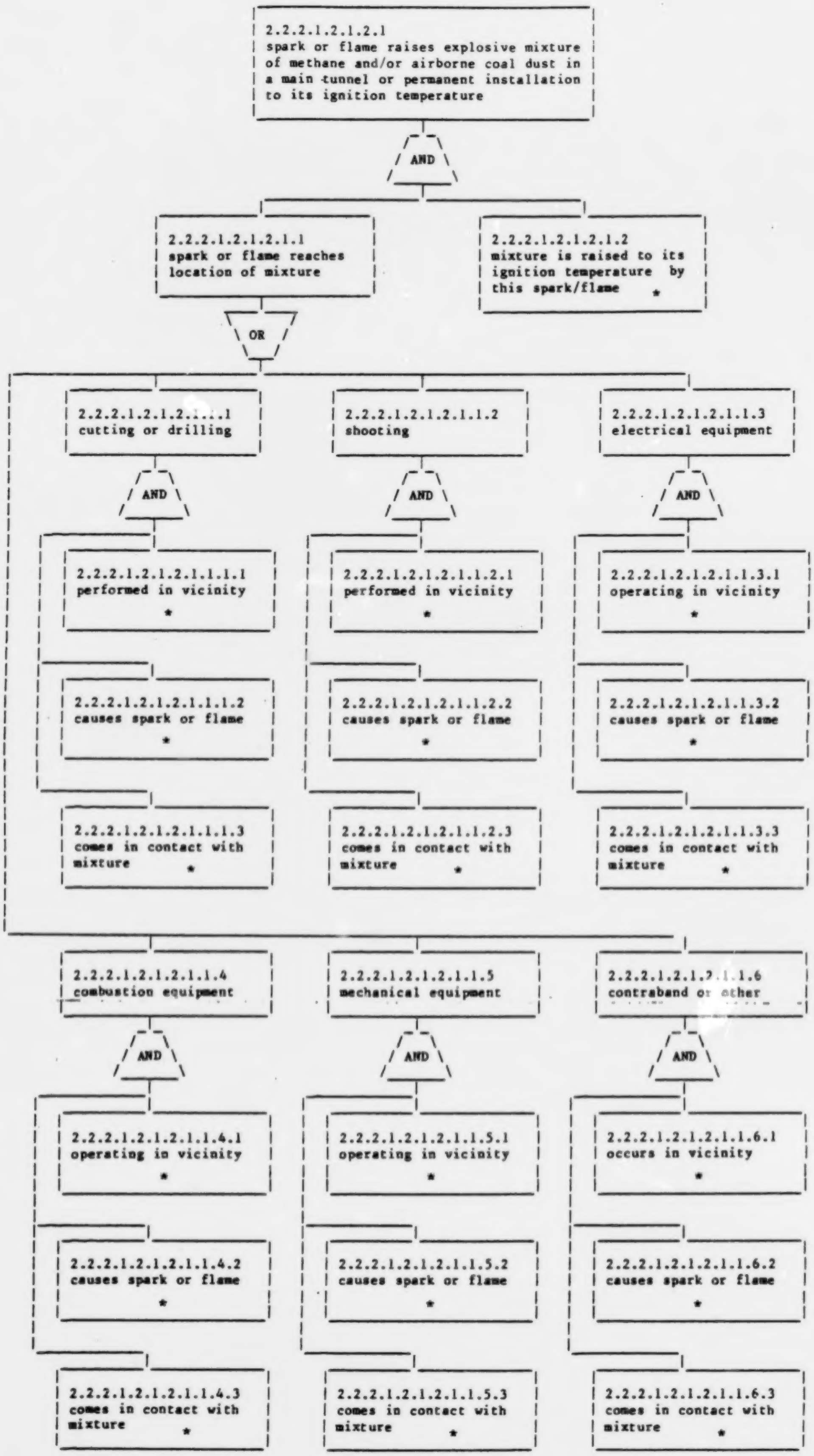

1.3.2.2.3.2.1
spark or flame raises imported flammable material in the return gate road of a working panel to its ignition temperature
AND
1.3.2.2.3.2.1.1
spark or flame comes in contact with material
1.3.2.2.3.2.1.2
material is raised to its ignition temperature by this spark/flame *
OR
1.3.2.2.3.2.1.1.1
cutting or drilling
1.3.2.2.3.2.1.1.2
shooting
1.3.2.2.3.2.1.1.3
electrical equipment
AND
AND
AND
1.3.2.2.3.2.1.1.1.1
performed in vicinity *
1.3.2.2.3.2.1.1.2.1
performed in vicinity *
1.3.2.2.3.2.1.1.3.1
operating in vicinity *
1.3.2.2.3.2.1.1.1.2
causes spark or flame *
1.3.2.2.3.2.1.1.2.2
causes spark or flame *
1.3.2.2.3.2.1.1.3.2
causes spark or flame *
1.3.2.2.3.2.1.1.1.3
comes in contact with material *
1.3.2.2.3.2.1.1.2.3
comes in contact with material *
1.3.2.2.3.2.1.1.3.3
comes in contact with material *
1.3.2.2.3.2.1.1.4
combustion equipment
1.3.2.2.3.2.1.1.5
mechanical equipment
1.3.2.2.3.2.1.1.6
contraband or other
AND
AND
AND
1.3.2.2.3.2.1.1.4.1
operating in vicinity *
1.3.2.2.3.2.1.1.5.1
operating in vicinity *
1.3.2.2.3.2.1.1.6.1
occurs in vicinity *
1.3.2.2.3.2.1.1.4.2
causes spark or flame *
1.3.2.2.3.2.1.1.5.2
causes spark or flame *
1.3.2.2.3.2.1.1.6.2
causes spark or flame *
1.3.2.2.3.2.1.1.4.3
comes in contact with material *
1.3.2.2.3.2.1.1.5.3
comes in contact with material *
1.3.2.2.3.2.1.1.6.3
comes in contact with material *

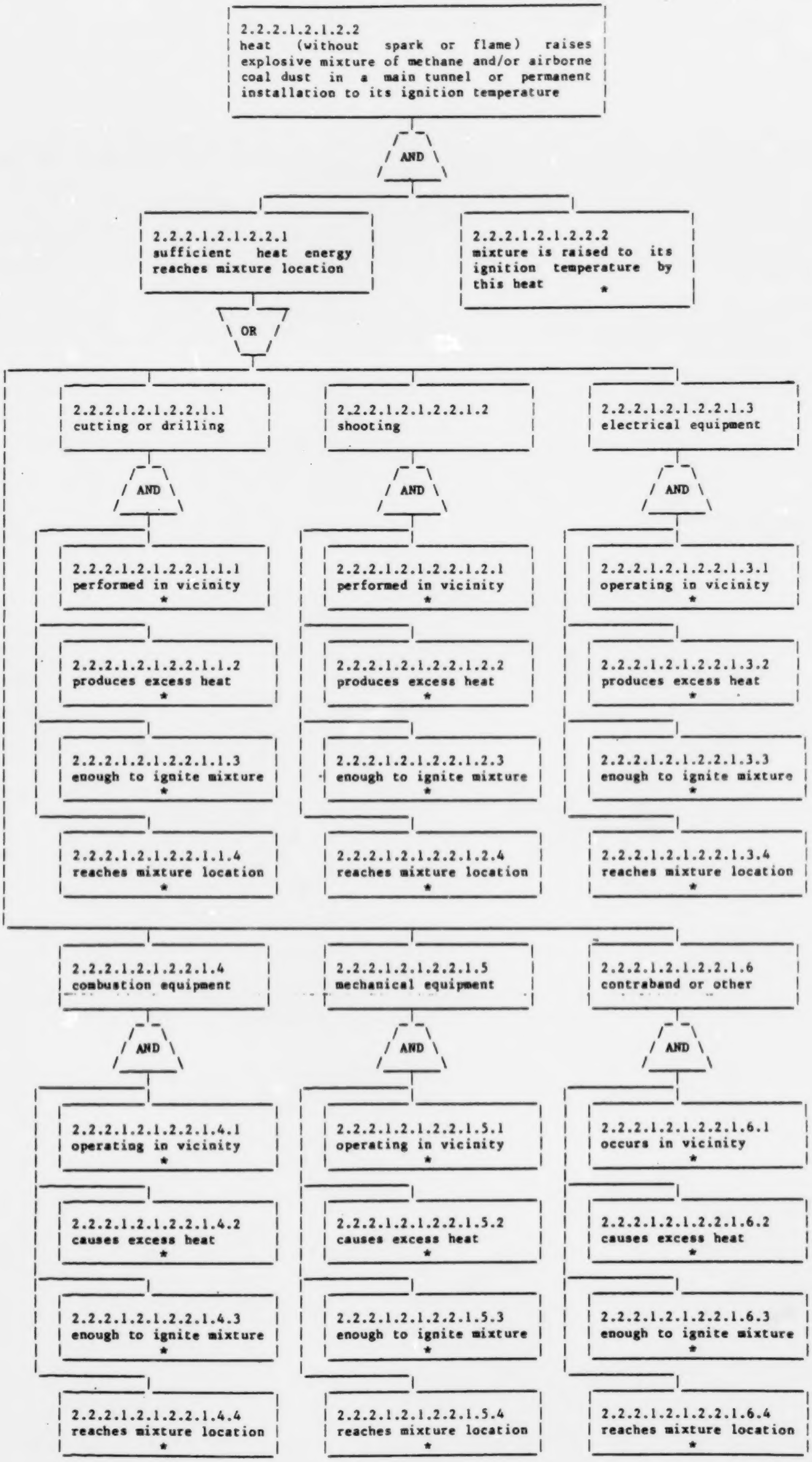

1.3.2.2.3.2.2
heat (without spark or flame) raises imported flammable material in the return gate road of a working panel to its ignition temperature
AND
1.3.2.2.3.2.2.1
sufficient heat energy reaches location of material
1.3.2.2.3.2.2.2
material is raised to its ignition temperature by this heat *
OR
1.3.2.2.3.2.2.1.1
cutting or drilling
1.3.2.2.3.2.2.1.2
shooting
1.3.2.2.3.2.2.1.3
electrical equipment
AND
AND
AND
1.3.2.2.3.2.2.1.1.1
performed in vicinity *
1.3.2.2.3.2.2.1.1.2
produces excess heat *
1.3.2.2.3.2.2.1.1.3
enough to ignite material *
1.3.2.2.3.2.2.1.1.4
reaches material location *
1.3.2.2.3.2.2.1.2.1
performed in vicinity *
1.3.2.2.3.2.2.1.2.2
produces excess heat *
1.3.2.2.3.2.2.1.2.3
enough to ignite material *
1.3.2.2.3.2.2.1.2.4
reaches material location *
1.3.2.2.3.2.2.1.3.1
operating in vicinity *
1.3.2.2.3.2.2.1.3.2
produces excess heat *
1.3.2.2.3.2.2.1.3.3
enough to ignite material *
1.3.2.2.3.2.2.1.3.4
reaches material location *
1.3.2.2.3.2.2.1.4
combustion equipment
1.3.2.2.3.2.2.1.5
mechanical equipment
1.3.2.2.3.2.2.1.6
contraband or other
AND
AND
AND
1.3.2.2.3.2.2.1.4.1
operating in vicinity *
1.3.2.2.3.2.2.1.4.2
causes excess heat *
1.3.2.2.3.2.2.1.4.3
enough to ignite material *
1.3.2.2.3.2.2.1.4.4
reaches material location *
1.3.2.2.3.2.2.1.5.1
operating in vicinity *
1.3.2.2.3.2.2.1.5.2
causes excess heat *
1.3.2.2.3.2.2.1.5.3
enough to ignite material *
1.3.2.2.3.2.2.1.5.4
reaches material location *
1.3.2.2.3.2.2.1.6.1
occurs in vicinity *
1.3.2.2.3.2.2.1.6.2
causes excess heat *
1.3.2.2.3.2.2.1.6.3
enough to ignite material *
1.3.2.2.3.2.2.1.6.4
reaches material location *

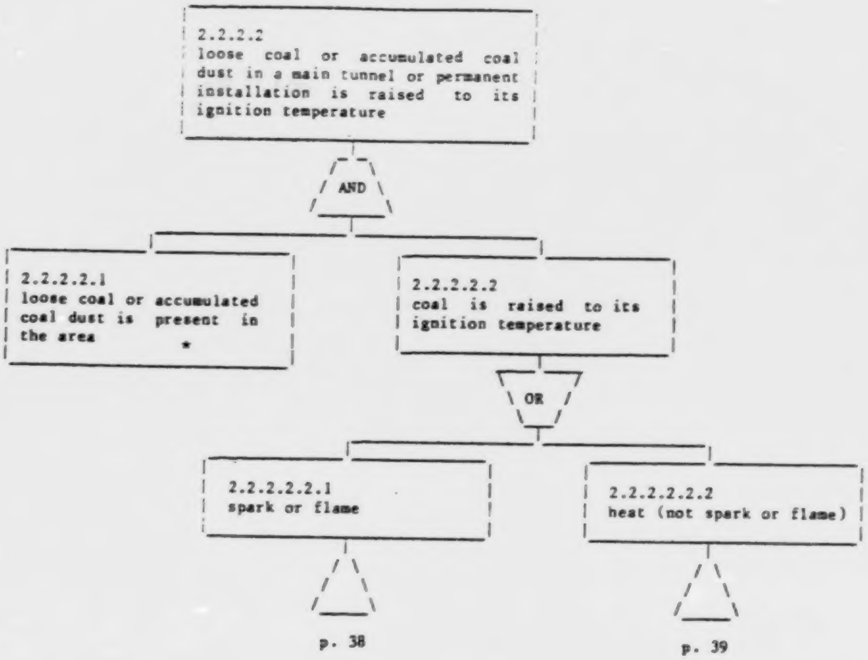

1.4
initiation of fire in the gob area of a working panel
OR
1.4.1
spontaneous combustion of coal or other material
1.4.2
ignition of a combustible material in the area by an external heat source
AND
1.4.2.1
level of oxygen in the gob is sufficient for ignition
*
1.4.2.2
a combustible material is raised to ignition temp.
*
AND
1.4.1.1
coal or other material in the gob prone to spontaneous combustion
*
1.4.1.2
high enough temperatures in gob (no dissipation)
*
1.4.1.3
air-flow through gob allows enough oxygen for self-heating
*
1.4.1.4
air flow not dissipating enough heat to prevent spontaneous combustion
*

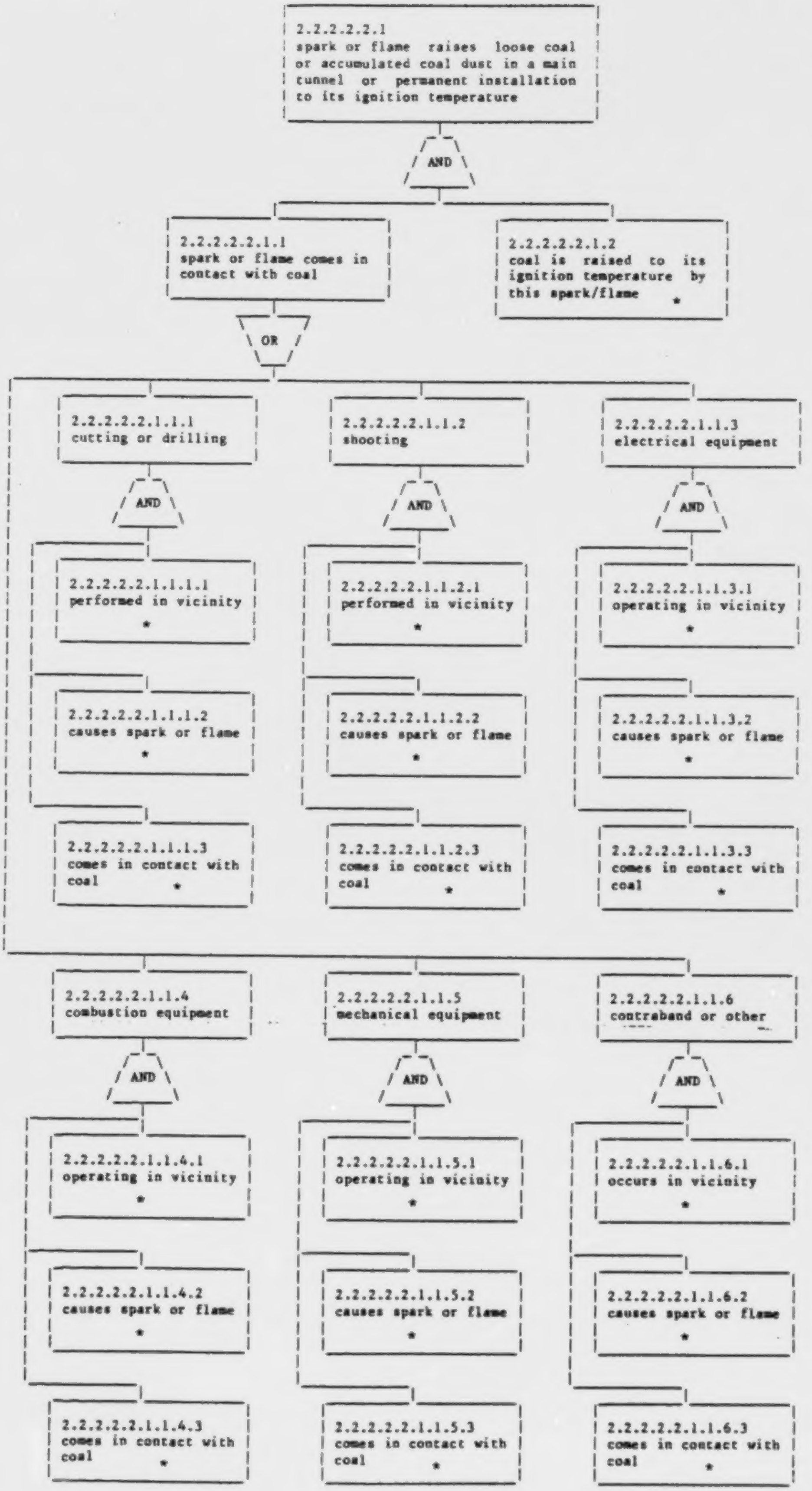

2
initiation of fire in a main tunnel or permanent installation
OR
2.1
spontaneous combustion of coal in the seam
2.2
ignition of a combustible material in the area by an external heat source
AND
2.2.1
level of oxygen in the air is sufficient
*
2.2.2
a combustible material is raised to ignition temp.
OR
AND
2.1.1
coal in seam prone to spontaneous combustion
*
2.1.2
high enough temperatures in seam (no dissipation)
*
2.2.2.1
explosive mixture of methane and/or airborne coal dust
p. 34
2.1.3
air-flow through seam allows enough oxygen in contact with coal
*
2.1.4
air flow not dissipating enough heat to prevent spontaneous combustion
*
2.2.2.2
loose coal or accumulated coal dust
p. 36
2.2.2.3
imported flammable material
p. 40

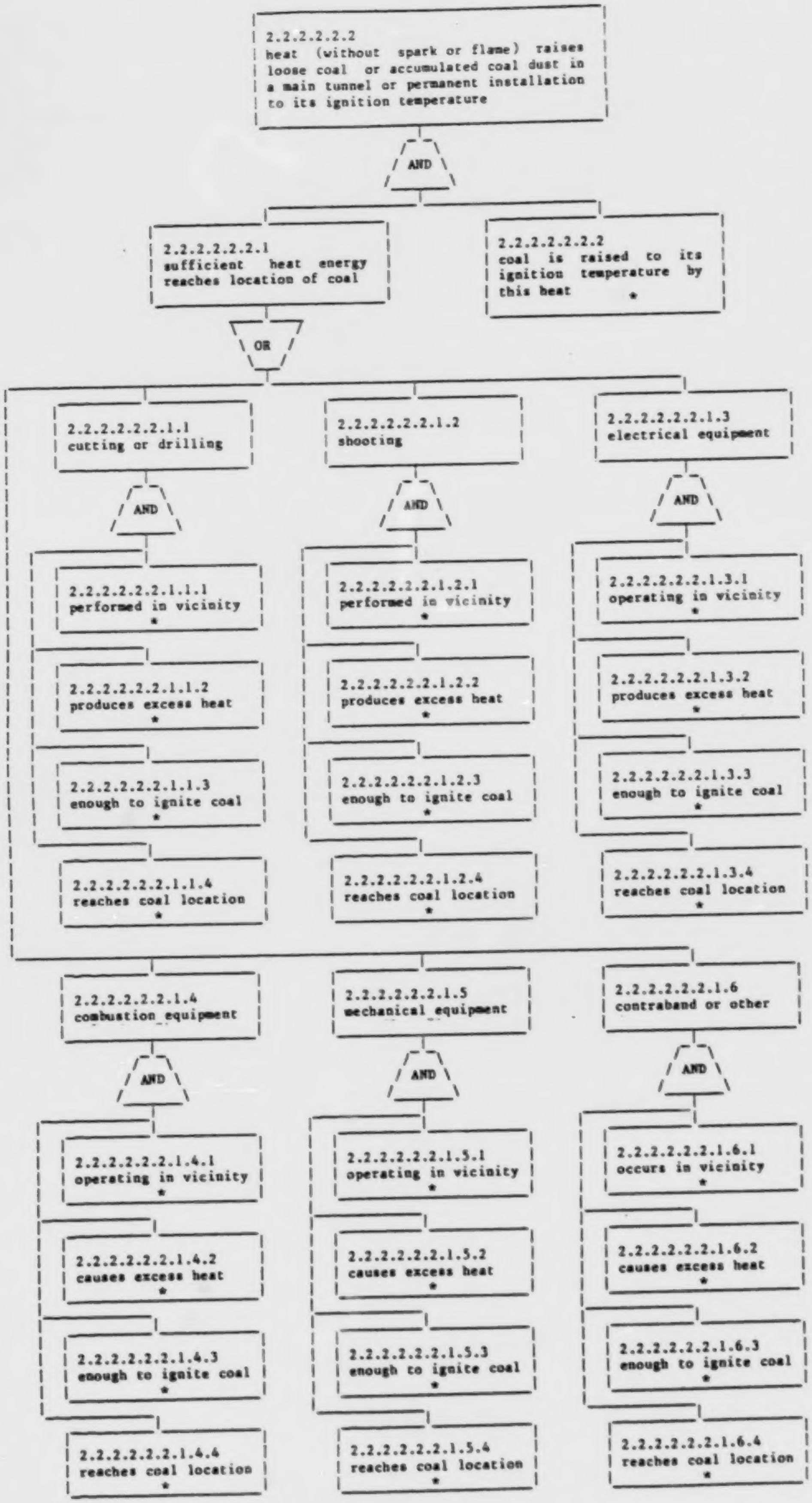

2.2.2.1 explosive mixture of methane and/or airborne coal dust in a main tunnel or permanent installation is raised to its ignition temperature
AND
2.2.2.1.1 explosive mixture of methane and/or coal dust is present in the area *
2.2.2.1.2 mixture is raised to its ignition temperature
OR
2.2.2.1.2.1 panel is not evacuated and mixture is raised to its ignition temperature
2.2.2.1.2.2 panel is evacuated and mixture is raised to its ignition temperature
AND
AND
2.2.2.1.2.1.1 panel not evacuated *
2.2.2.1.2.1.2 mixture is raised to its ignition temperature (given no evacuation)
2.2.2.1.2.2.1 panel is evacuated *
2.2.2.1.2.2.2 mixture is raised to its ignition temperature (given evacuation) *
OR
2.2.2.1.2.1.2.1 spark or flame
2.2.2.1.2.1.2.2 heat (not spark or flame)
p. 35
p. 36

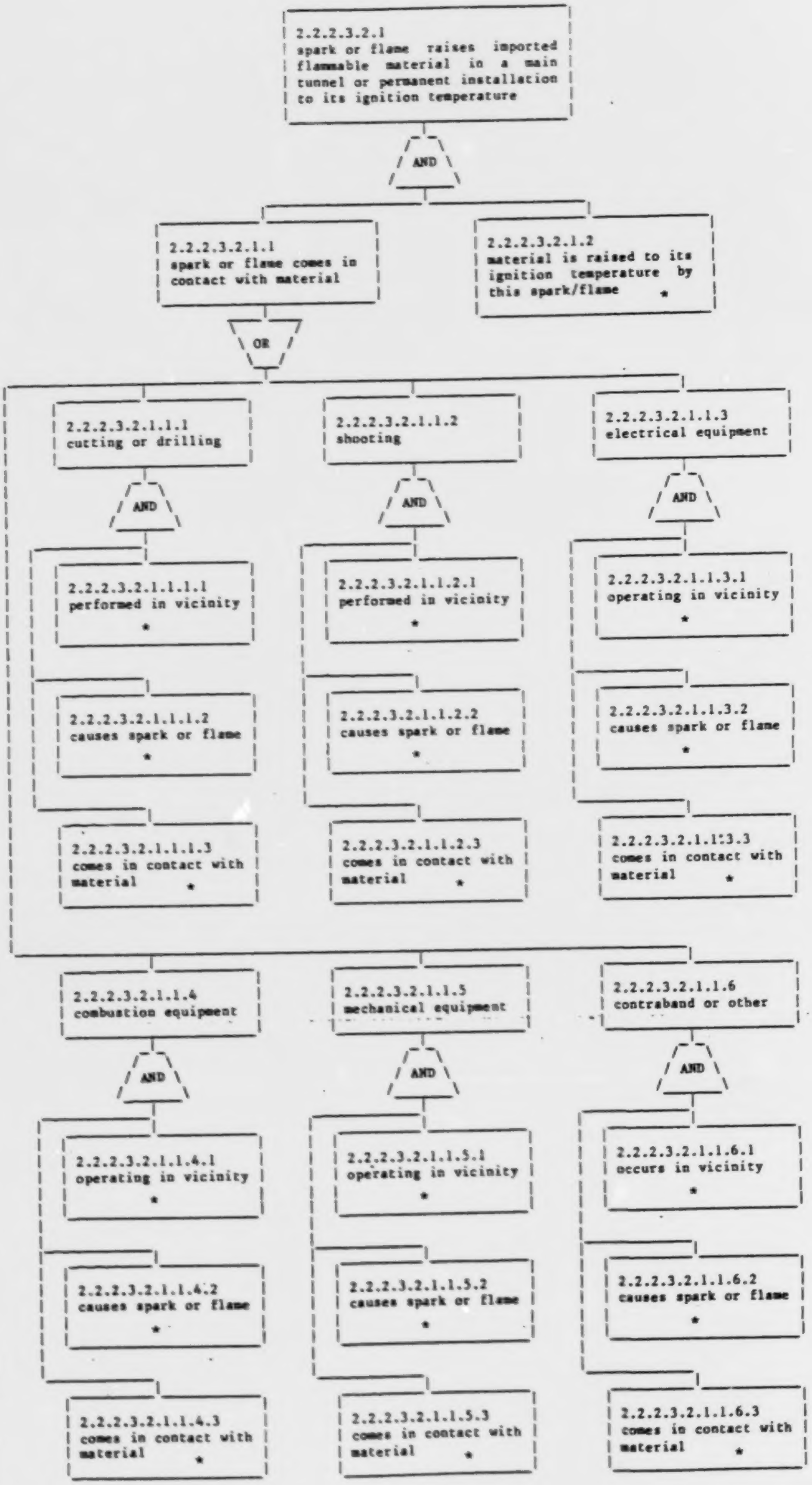

2.2.2.1.2.1.2.1
spark or flame raises explosive mixture of methane and/or airborne coal dust in a main tunnel or permanent installation to its ignition temperature
AND
2.2.2.1.2.1.2.1.1
spark or flame reaches location of mixture
2.2.2.1.2.1.2.1.2
mixture is raised to its ignition temperature by this spark/flame *
OR
2.2.2.1.2.1.2.1.1.1
cutting or drilling
2.2.2.1.2.1.2.1.1.2
shooting
2.2.2.1.2.1.2.1.1.3
electrical equipment
AND
AND
AND
2.2.2.1.2.1.2.1.1.1.1
performed in vicinity *
2.2.2.1.2.1.2.1.1.2.1
performed in vicinity *
2.2.2.1.2.1.2.1.1.3.1
operating in vicinity *
2.2.2.1.2.1.2.1.1.1.2
causes spark or flame *
2.2.2.1.2.1.2.1.1.2.2
causes spark or flame *
2.2.2.1.2.1.2.1.1.3.2
causes spark or flame *
2.2.2.1.2.1.2.1.1.1.3
comes in contact with mixture *
2.2.2.1.2.1.2.1.1.2.3
comes in contact with mixture *
2.2.2.1.2.1.2.1.1.3.3
comes in contact with mixture *
2.2.2.1.2.1.2.1.1.4
combustion equipment
2.2.2.1.2.1.2.1.1.5
mechanical equipment
2.2.2.1.2.1.2.1.1.6
contraband or other
AND
AND
AND
2.2.2.1.2.1.2.1.1.4.1
operating in vicinity *
2.2.2.1.2.1.2.1.1.5.1
operating in vicinity *
2.2.2.1.2.1.2.1.1.6.1
occurs in vicinity *
2.2.2.1.2.1.2.1.1.4.2
causes spark or flame *
2.2.2.1.2.1.2.1.1.5.2
causes spark or flame *
2.2.2.1.2.1.2.1.1.6.2
causes spark or flame *
2.2.2.1.2.1.2.1.1.4.3
comes in contact with mixture *
2.2.2.1.2.1.2.1.1.5.3
comes in contact with mixture *
2.2.2.1.2.1.2.1.1.6.3
comes in contact with mixture *

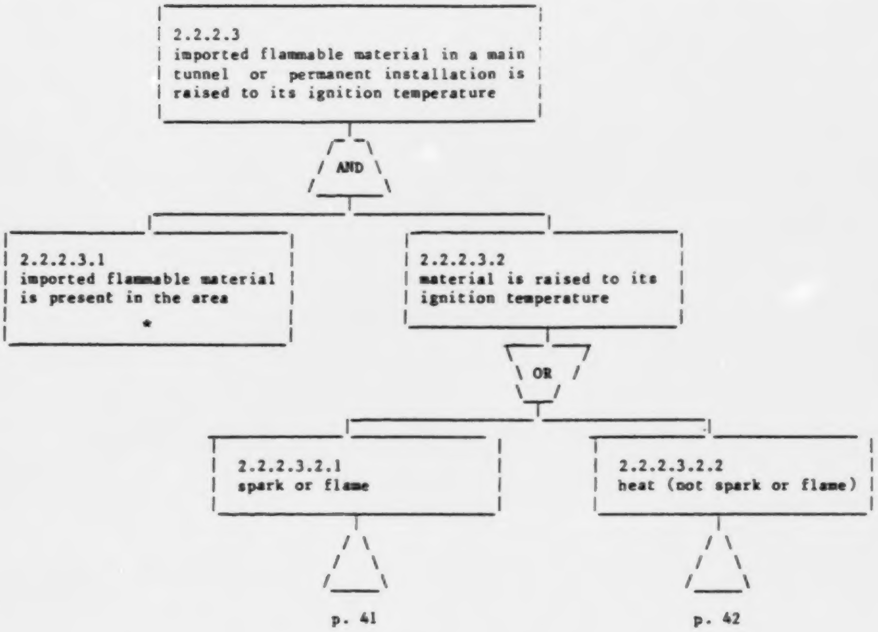

2.2.2.1.2.1.2.2
heat (without spark or flame) raises explosive mixture of methane and/or airborne coal dust in a main tunnel or permanent installation to its ignition temperature
AND
2.2.2.1.2.1.2.2.1
sufficient heat energy reaches mixture location
2.2.2.1.2.1.2.2.2
mixture is raised to its ignition temperature by this heat
*
OR
2.2.2.1.2.1.2.2.1.1
cutting or drilling
2.2.2.1.2.1.2.2.1.2
shooting
2.2.2.1.2.1.2.2.1.3
electrical equipment
AND
AND
AND
2.2.2.1.2.1.2.2.1.1.1
performed in vicinity
*
2.2.2.1.2.1.2.2.1.2.1
performed in vicinity
*
2.2.2.1.2.1.2.2.1.3.1
operating in vicinity
*
2.2.2.1.2.1.2.2.1.1.2
produces excess heat
*
2.2.2.1.2.1.2.2.1.2.2
produces excess heat
*
2.2.2.1.2.1.2.2.1.3.2
produces excess heat
*
2.2.2.1.2.1.2.2.1.1.3
enough to ignite mixture
*
2.2.2.1.2.1.2.2.1.2.3
enough to ignite mixture
*
2.2.2.1.2.1.2.2.1.3.3
enough to ignite mixture
*
2.2.2.1.2.1.2.2.1.1.4
reaches mixture location
*
2.2.2.1.2.1.2.2.1.2.4
reaches mixture location
*
2.2.2.1.2.1.2.2.1.3.4
reaches mixture location
*
2.2.2.1.2.1.2.2.1.4
combustion equipment
2.2.2.1.2.1.2.2.1.5
mechanical equipment
2.2.2.1.2.1.2.2.1.6
contraband or other
AND
AND
AND
2.2.2.1.2.1.2.2.1.4.1
operating in vicinity
*
2.2.2.1.2.1.2.2.1.5.1
operating in vicinity
*
2.2.2.1.2.1.2.2.1.6.1
occurs in vicinity
*
2.2.2.1.2.1.2.2.1.4.2
causes excess heat
*
2.2.2.1.2.1.2.2.1.5.2
causes excess heat
*
2.2.2.1.2.1.2.2.1.6.2
causes excess heat
*
2.2.2.1.2.1.2.2.1.4.3
enough to ignite mixture
*
2.2.2.1.2.1.2.2.1.5.3
enough to ignite mixture
*
2.2.2.1.2.1.2.2.1.6.3
enough to ignite mixture
*
2.2.2.1.2.1.2.2.1.4.4
reaches mixture location
*
2.2.2.1.2.1.2.2.1.5.4
reaches mixture location
*
2.2.2.1.2.1.2.2.1.6.4
reaches mixture location
*

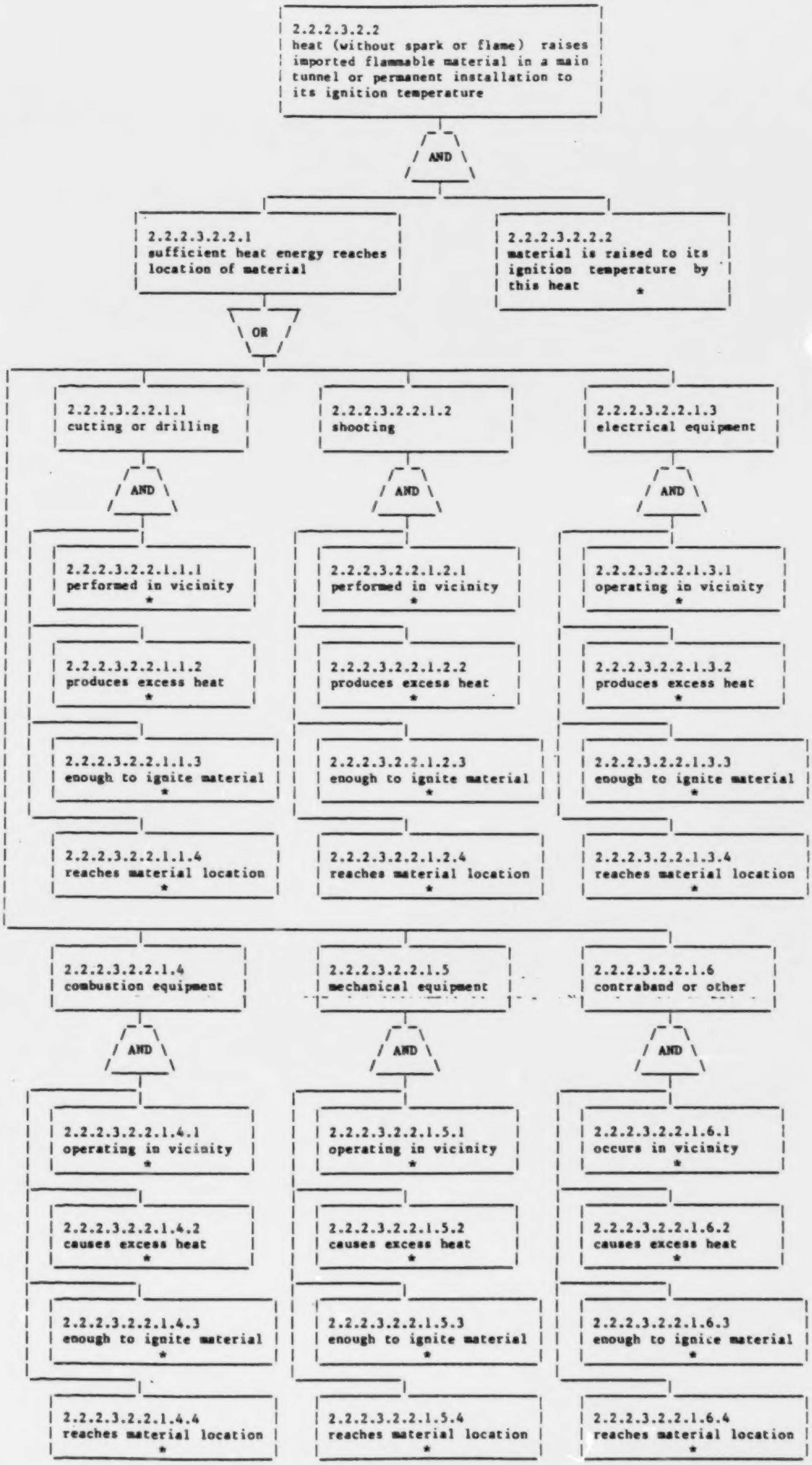

2.2.2.2
loose coal or accumulated coal dust in a main tunnel or permanent installation is raised to its ignition temperature
AND
2.2.2.2.1
loose coal or accumulated coal dust is present in the area *
2.2.2.2.2
coal is raised to its ignition temperature
OR
2.2.2.2.2.1
spark or flame
2.2.2.2.2.2
heat (not spark or flame)
p. 38
p. 39

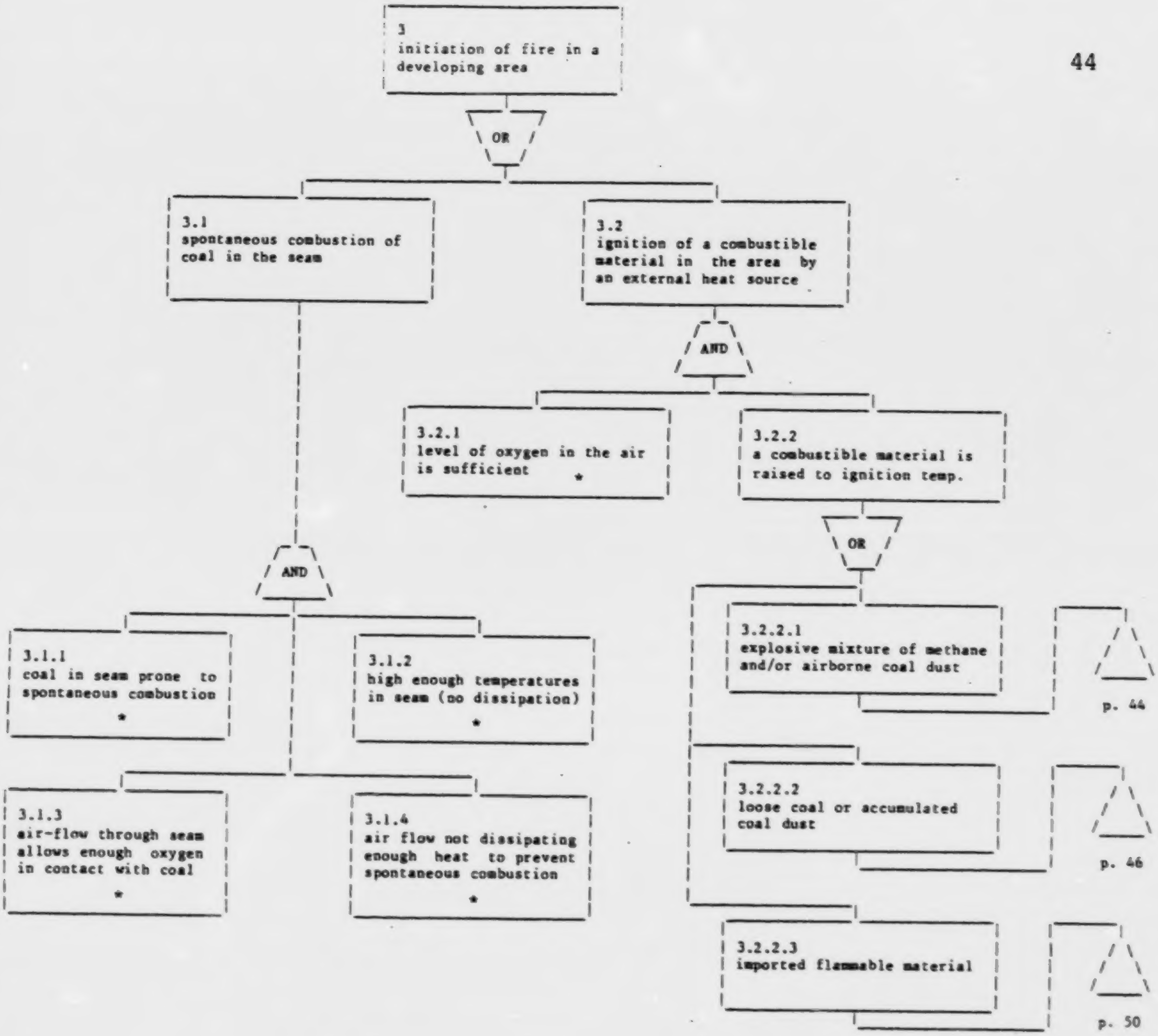

2.2.2.2.2.1
spark or flame raises loose coal or accumulated coal dust in a main tunnel or permanent installation to its ignition temperature
AND
2.2.2.2.2.1.1
spark or flame comes in contact with coal
2.2.2.2.2.1.2
coal is raised to its ignition temperature by this spark/flame *
OR
2.2.2.2.2.1.1.1
cutting or drilling
2.2.2.2.2.1.1.2
shooting
2.2.2.2.2.1.1.3
electrical equipment
AND
AND
AND
2.2.2.2.2.1.1.1.1
performed in vicinity *
2.2.2.2.2.1.1.2.1
performed in vicinity *
2.2.2.2.2.1.1.3.1
operating in vicinity *
2.2.2.2.2.1.1.1.2
causes spark or flame *
2.2.2.2.2.1.1.2.2
causes spark or flame *
2.2.2.2.2.1.1.3.2
causes spark or flame *
2.2.2.2.2.1.1.1.3
comes in contact with coal *
2.2.2.2.2.1.1.2.3
comes in contact with coal *
2.2.2.2.2.1.1.3.3
comes in contact with coal *
2.2.2.2.2.1.1.4
combustion equipment
2.2.2.2.2.1.1.5
mechanical equipment
2.2.2.2.2.1.1.6
contraband or other
AND
AND
AND
2.2.2.2.2.1.1.4.1
operating in vicinity *
2.2.2.2.2.1.1.5.1
operating in vicinity *
2.2.2.2.2.1.1.6.1
occurs in vicinity *
2.2.2.2.2.1.1.4.2
causes spark or flame *
2.2.2.2.2.1.1.5.2
causes spark or flame *
2.2.2.2.2.1.1.6.2
causes spark or flame *
2.2.2.2.2.1.1.4.3
comes in contact with coal *
2.2.2.2.2.1.1.5.3
comes in contact with coal *
2.2.2.2.2.1.1.6.3
comes in contact with coal *

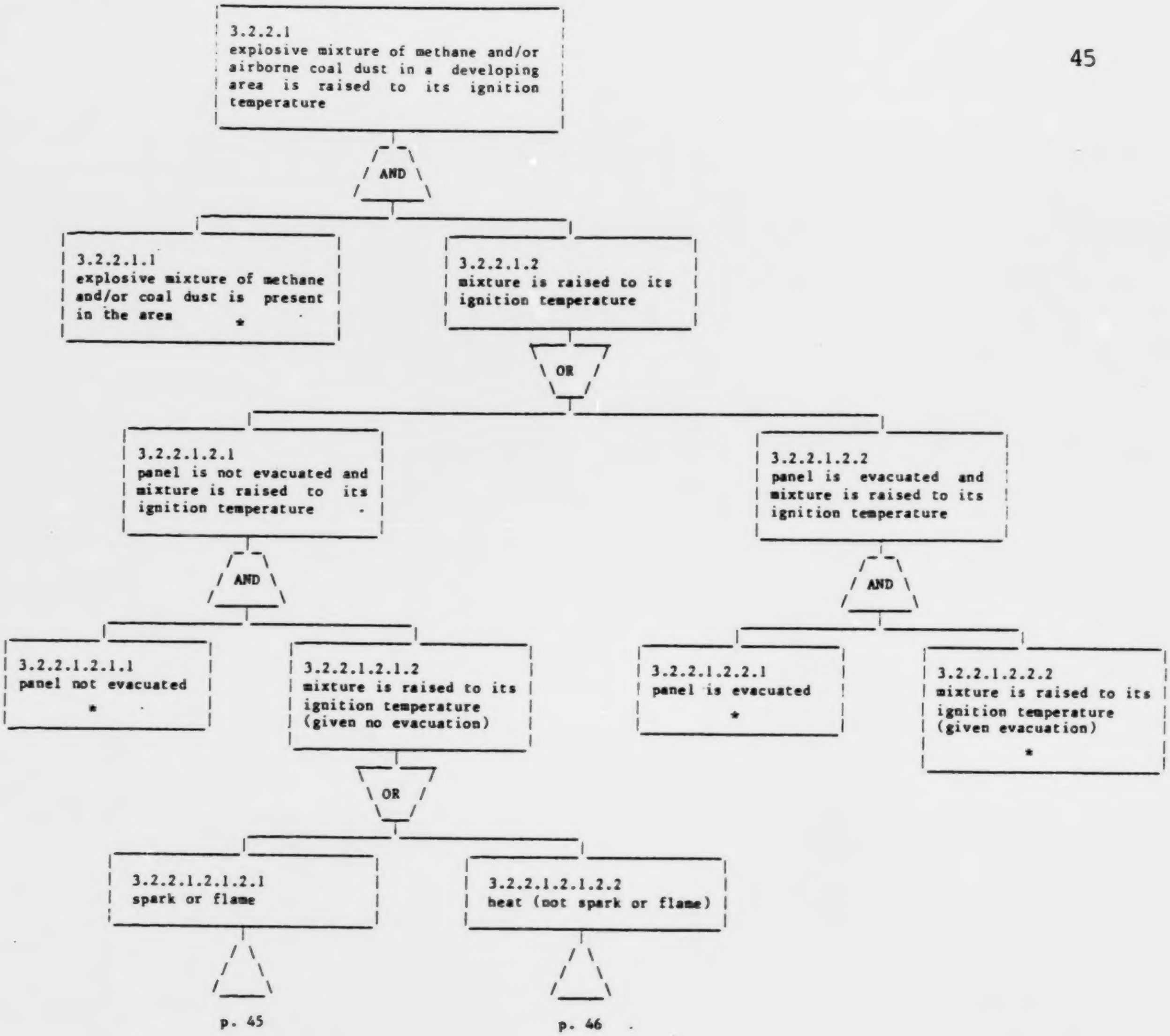

2.2.2.2.2.2
heat (without spark or flame) raises loose coal or accumulated coal dust in a main tunnel or permanent installation to its ignition temperature
AND
2.2.2.2.2.2.1
sufficient heat energy reaches location of coal
2.2.2.2.2.2.2
coal is raised to its ignition temperature by this heat *
OR
2.2.2.2.2.2.1.1
cutting or drilling
2.2.2.2.2.2.1.2
shooting
2.2.2.2.2.2.1.3
electrical equipment
AND
AND
AND
2.2.2.2.2.2.1.1.1
performed in vicinity *
2.2.2.2.2.2.1.1.2
produces excess heat *
2.2.2.2.2.2.1.1.3
enough to ignite coal *
2.2.2.2.2.2.1.1.4
reaches coal location *
2.2.2.2.2.2.1.2.1
performed in vicinity *
2.2.2.2.2.2.1.2.2
produces excess heat *
2.2.2.2.2.2.1.2.3
enough to ignite coal *
2.2.2.2.2.2.1.2.4
reaches coal location *
2.2.2.2.2.2.1.3.1
operating in vicinity *
2.2.2.2.2.2.1.3.2
produces excess heat *
2.2.2.2.2.2.1.3.3
enough to ignite coal *
2.2.2.2.2.2.1.3.4
reaches coal location *
2.2.2.2.2.2.1.4
combustion equipment
2.2.2.2.2.2.1.5
mechanical equipment
2.2.2.2.2.2.1.6
contraband or other
AND
AND
AND
2.2.2.2.2.2.1.4.1
operating in vicinity *
2.2.2.2.2.2.1.4.2
causes excess heat *
2.2.2.2.2.2.1.4.3
enough to ignite coal *
2.2.2.2.2.2.1.4.4
reaches coal location *
2.2.2.2.2.2.1.5.1
operating in vicinity *
2.2.2.2.2.2.1.5.2
causes excess heat *
2.2.2.2.2.2.1.5.3
enough to ignite coal *
2.2.2.2.2.2.1.5.4
reaches coal location *
2.2.2.2.2.2.1.6.1
occurs in vicinity *
2.2.2.2.2.2.1.6.2
causes excess heat *
2.2.2.2.2.2.1.6.3
enough to ignite coal *
2.2.2.2.2.2.1.6.4
reaches coal location *

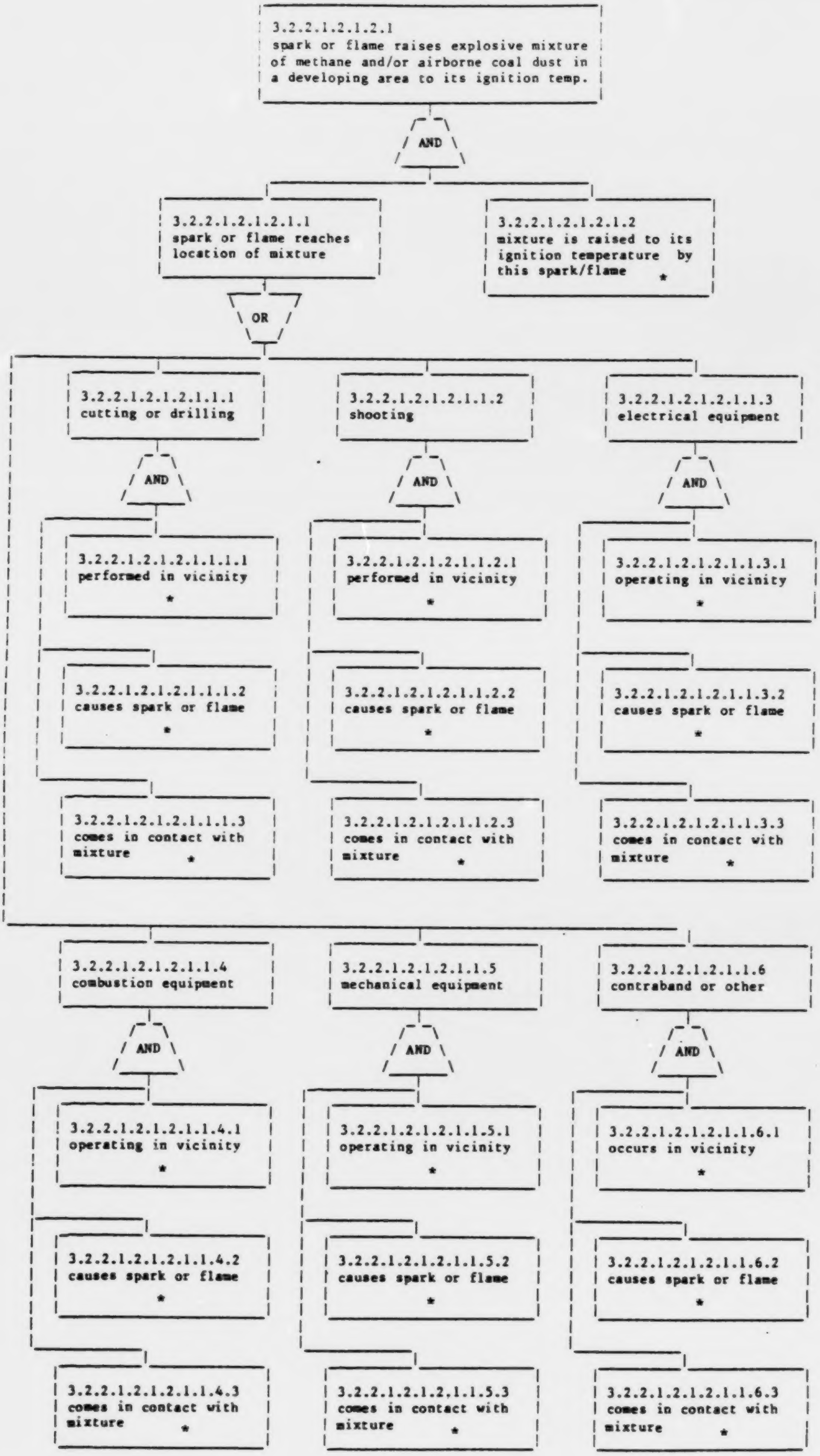

2.2.2.3.2.1 spark or flame raises imported flammable material in a main tunnel or permanent installation to its ignition temperature
AND
2.2.2.3.2.1.1 spark or flame comes in contact with material
2.2.2.3.2.1.2 material is raised to its ignition temperature by this spark/flame *
OR
2.2.2.3.2.1.1.1 cutting or drilling
2.2.2.3.2.1.1.2 shooting
2.2.2.3.2.1.1.3 electrical equipment
AND
AND
AND
2.2.2.3.2.1.1.1.1 performed in vicinity *
2.2.2.3.2.1.1.2.1 performed in vicinity *
2.2.2.3.2.1.1.3.1 operating in vicinity *
2.2.2.3.2.1.1.1.2 causes spark or flame *
2.2.2.3.2.1.1.2.2 causes spark or flame *
2.2.2.3.2.1.1.3.2 causes spark or flame *
2.2.2.3.2.1.1.1.3 comes in contact with material *
2.2.2.3.2.1.1.2.3 comes in contact with material *
2.2.2.3.2.1.1.3.3 comes in contact with material *
2.2.2.3.2.1.1.4 combustion equipment
2.2.2.3.2.1.1.5 mechanical equipment
2.2.2.3.2.1.1.6 contraband or other
AND
AND
AND
2.2.2.3.2.1.1.4.1 operating in vicinity *
2.2.2.3.2.1.1.5.1 operating in vicinity *
2.2.2.3.2.1.1.6.1 occurs in vicinity *
2.2.2.3.2.1.1.4.2 causes spark or flame *
2.2.2.3.2.1.1.5.2 causes spark or flame *
2.2.2.3.2.1.1.6.2 causes spark or flame *
2.2.2.3.2.1.1.4.3 comes in contact with material *
2.2.2.3.2.1.1.5.3 comes in contact with material *
2.2.2.3.2.1.1.6.3 comes in contact with material *

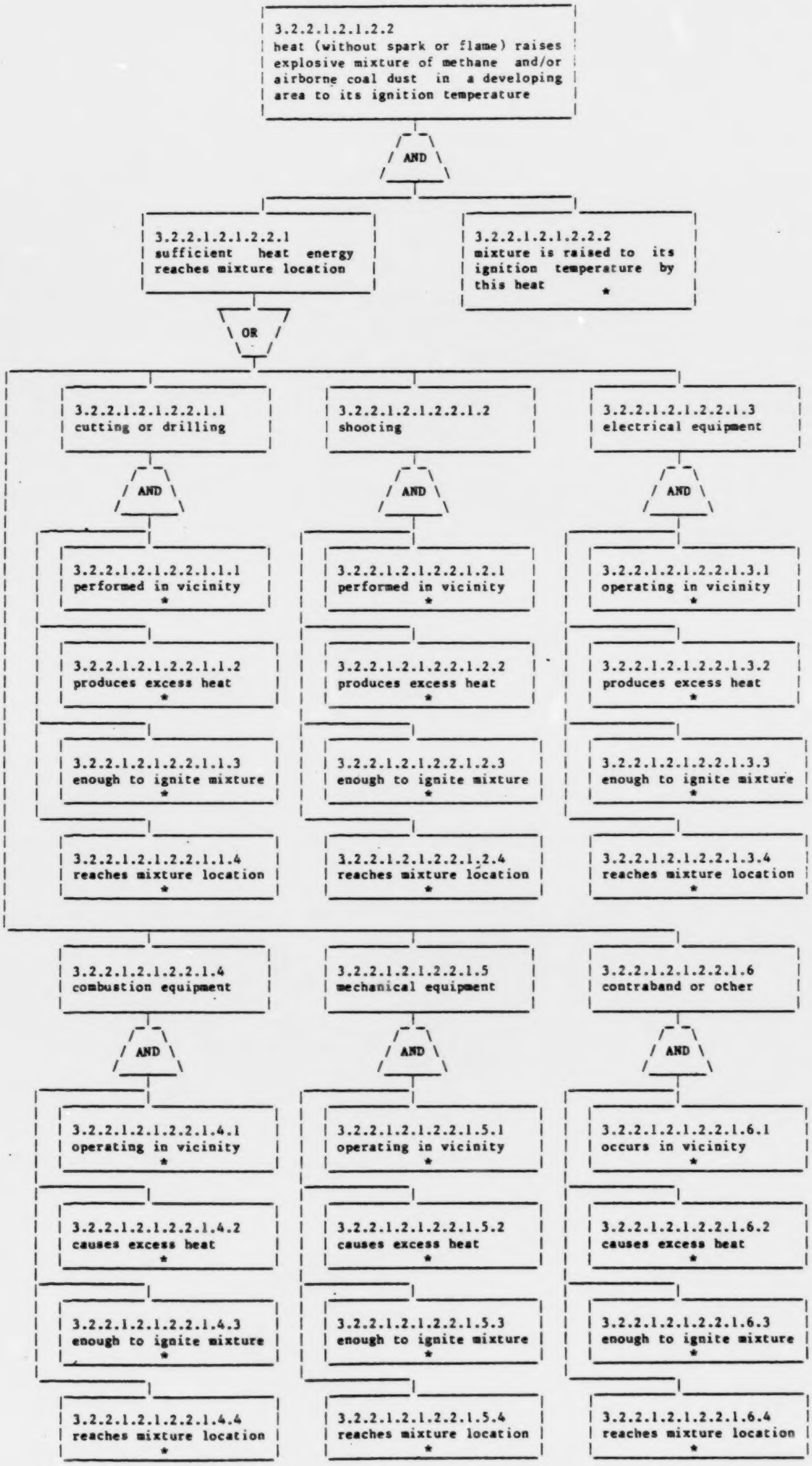

2.2.2.3
imported flammable material in a main tunnel or permanent installation is raised to its ignition temperature
AND
2.2.2.3.1
imported flammable material is present in the area
*
2.2.2.3.2
material is raised to its ignition temperature
OR
2.2.2.3.2.1
spark or flame
2.2.2.3.2.2
heat (not spark or flame)
p. 41
p. 42

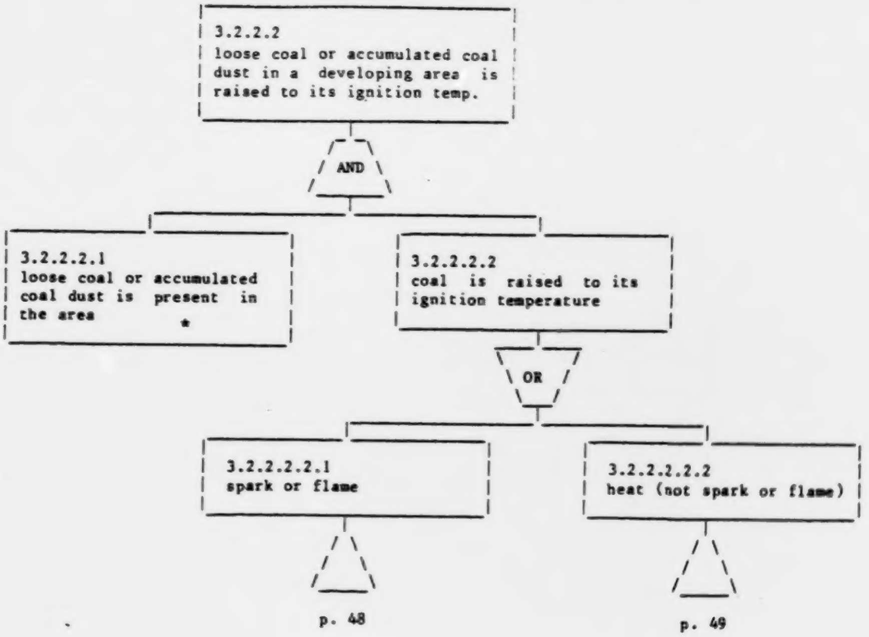

2.2.2.3.2.2
heat (without spark or flame) raises imported flammable material in a main tunnel or permanent installation to its ignition temperature
AND
2.2.2.3.2.2.1
sufficient heat energy reaches location of material
2.2.2.3.2.2.2
material is raised to its ignition temperature by this heat
*
OR
2.2.2.3.2.2.1.1
cutting or drilling
2.2.2.3.2.2.1.2
shooting
2.2.2.3.2.2.1.3
electrical equipment
AND
AND
AND
2.2.2.3.2.2.1.1.1
performed in vicinity
*
2.2.2.3.2.2.1.2.1
performed in vicinity
*
2.2.2.3.2.2.1.3.1
operating in vicinity
*
2.2.2.3.2.2.1.1.2
produces excess heat
*
2.2.2.3.2.2.1.2.2
produces excess heat
*
2.2.2.3.2.2.1.3.2
produces excess heat
*
2.2.2.3.2.2.1.1.3
enough to ignite material
*
2.2.2.3.2.2.1.2.3
enough to ignite material
*
2.2.2.3.2.2.1.3.3
enough to ignite material
*
2.2.2.3.2.2.1.1.4
reaches material location
*
2.2.2.3.2.2.1.2.4
reaches material location
*
2.2.2.3.2.2.1.3.4
reaches material location
*
2.2.2.3.2.2.1.4
combustion equipment
2.2.2.3.2.2.1.5
mechanical equipment
2.2.2.3.2.2.1.6
contraband or other
AND
AND
AND
2.2.2.3.2.2.1.4.1
operating in vicinity
*
2.2.2.3.2.2.1.5.1
operating in vicinity
*
2.2.2.3.2.2.1.6.1
occurs in vicinity
*
2.2.2.3.2.2.1.4.2
causes excess heat
*
2.2.2.3.2.2.1.5.2
causes excess heat
*
2.2.2.3.2.2.1.6.2
causes excess heat
*
2.2.2.3.2.2.1.4.3
enough to ignite material
*
2.2.2.3.2.2.1.5.3
enough to ignite material
*
2.2.2.3.2.2.1.6.3
enough to ignice material
*
2.2.2.3.2.2.1.4.4
reaches material location
*
2.2.2.3.2.2.1.5.4
reaches material location
*
2.2.2.3.2.2.1.6.4
reaches material location
*

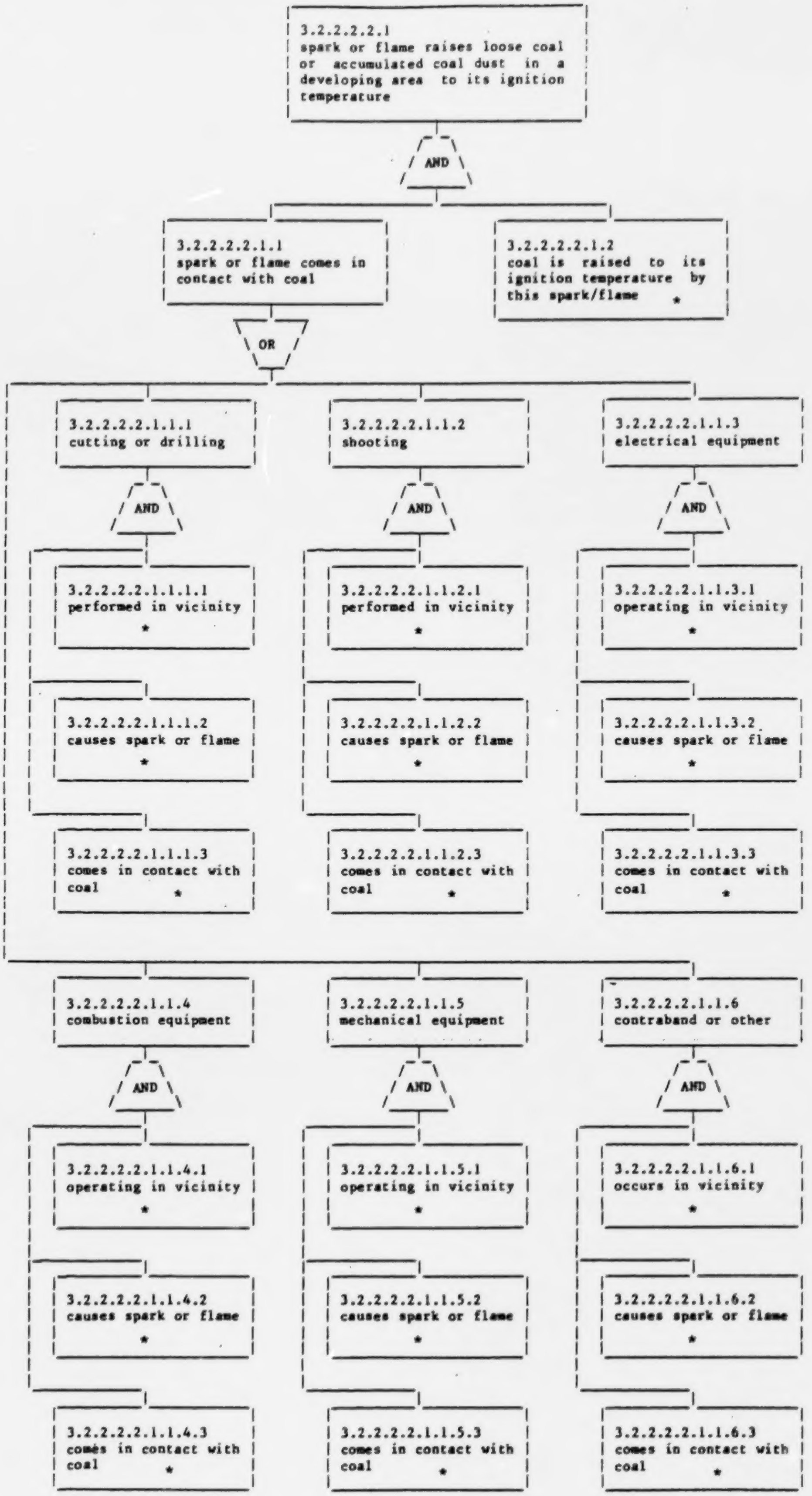

3
initiation of fire in a developing area
OR
3.1
spontaneous combustion of coal in the seam
3.2
ignition of a combustible material in the area by an external heat source
AND
3.2.1
level of oxygen in the air is sufficient
*
3.2.2
a combustible material is raised to ignition temp.
AND
3.1.1
coal in seam prone to spontaneous combustion
*
3.1.2
high enough temperatures in seam (no dissipation)
*
3.1.3
air-flow through seam allows enough oxygen in contact with coal
*
3.1.4
air flow not dissipating enough heat to prevent spontaneous combustion
*
OR
3.2.2.1
explosive mixture of methane and/or airborne coal dust
p. 44
3.2.2.2
loose coal or accumulated coal dust
p. 46
3.2.2.3
imported flammable material
p. 50

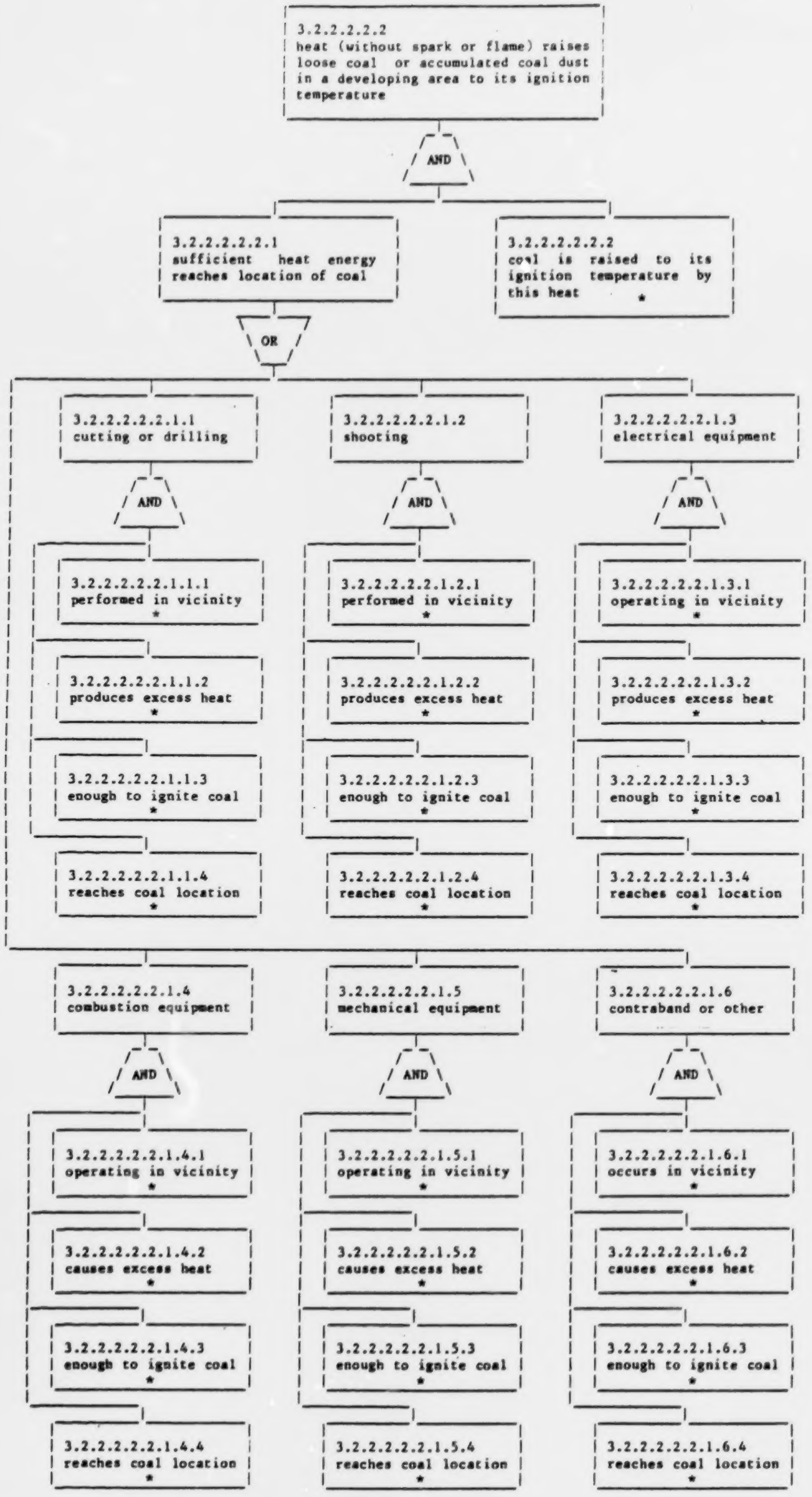

3.2.2.1
explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition temperature
AND
3.2.2.1.1
explosive mixture of methane and/or coal dust is present in the area
*
3.2.2.1.2
mixture is raised to its ignition temperature
OR
3.2.2.1.2.1
panel is not evacuated and mixture is raised to its ignition temperature
AND
3.2.2.1.2.1.1
panel not evacuated
*
3.2.2.1.2.1.2
mixture is raised to its ignition temperature (given no evacuation)
OR
3.2.2.1.2.1.2.1
spark or flame
p. 45
3.2.2.1.2.1.2.2
heat (not spark or flame)
p. 46
3.2.2.1.2.2
panel is evacuated and mixture is raised to its ignition temperature
AND
3.2.2.1.2.2.1
panel is evacuated
*
3.2.2.1.2.2.2
mixture is raised to its ignition temperature (given evacuation)
*


3.2.2.1.2.1.2.1
spark or flame raises explosive mixture of methane and/or airborne coal dust in a developing area to its ignition temp.
AND
3.2.2.1.2.1.2.1.1
spark or flame reaches location of mixture
3.2.2.1.2.1.2.1.2
mixture is raised to its ignition temperature by this spark/flame *
OR
3.2.2.1.2.1.2.1.1.1
cutting or drilling
3.2.2.1.2.1.2.1.1.2
shooting
3.2.2.1.2.1.2.1.1.3
electrical equipment
AND
AND
AND
3.2.2.1.2.1.2.1.1.1.1
performed in vicinity *
3.2.2.1.2.1.2.1.1.2.1
performed in vicinity *
3.2.2.1.2.1.2.1.1.3.1
operating in vicinity *
3.2.2.1.2.1.2.1.1.1.2
causes spark or flame *
3.2.2.1.2.1.2.1.1.2.2
causes spark or flame *
3.2.2.1.2.1.2.1.1.3.2
causes spark or flame *
3.2.2.1.2.1.2.1.1.1.3
comes in contact with mixture *
3.2.2.1.2.1.2.1.1.2.3
comes in contact with mixture *
3.2.2.1.2.1.2.1.1.3.3
comes in contact with mixture *
3.2.2.1.2.1.2.1.1.4
combustion equipment
3.2.2.1.2.1.2.1.1.5
mechanical equipment
3.2.2.1.2.1.2.1.1.6
contraband or other
AND
AND
AND
3.2.2.1.2.1.2.1.1.4.1
operating in vicinity *
3.2.2.1.2.1.2.1.1.5.1
operating in vicinity *
3.2.2.1.2.1.2.1.1.6.1
occurs in vicinity *
3.2.2.1.2.1.2.1.1.4.2
causes spark or flame *
3.2.2.1.2.1.2.1.1.5.2
causes spark or flame *
3.2.2.1.2.1.2.1.1.6.2
causes spark or flame *
3.2.2.1.2.1.2.1.1.4.3
comes in contact with mixture *
3.2.2.1.2.1.2.1.1.5.3
comes in contact with mixture *
3.2.2.1.2.1.2.1.1.6.3
comes in contact with mixture *


3.2.2.1.2.1.2.2
heat (without spark or flame) raises explosive mixture of methane and/or airborne coal dust in a developing area to its ignition temperature
AND
3.2.2.1.2.1.2.2.1
sufficient heat energy reaches mixture location
3.2.2.1.2.1.2.2.2
mixture is raised to its ignition temperature by this heat
*
OR
3.2.2.1.2.1.2.2.1.1
cutting or drilling
3.2.2.1.2.1.2.2.1.2
shooting
3.2.2.1.2.1.2.2.1.3
electrical equipment
AND
AND
AND
3.2.2.1.2.1.2.2.1.1.1
performed in vicinity
*
3.2.2.1.2.1.2.2.1.2.1
performed in vicinity
*
3.2.2.1.2.1.2.2.1.3.1
operating in vicinity
*
3.2.2.1.2.1.2.2.1.1.2
produces excess heat
*
3.2.2.1.2.1.2.2.1.2.2
produces excess heat
*
3.2.2.1.2.1.2.2.1.3.2
produces excess heat
*
3.2.2.1.2.1.2.2.1.1.3
enough to ignite mixture
*
3.2.2.1.2.1.2.2.1.2.3
enough to ignite mixture
*
3.2.2.1.2.1.2.2.1.3.3
enough to ignite mixture
*
3.2.2.1.2.1.2.2.1.1.4
reaches mixture location
*
3.2.2.1.2.1.2.2.1.2.4
reaches mixture location
*
3.2.2.1.2.1.2.2.1.3.4
reaches mixture location
*
3.2.2.1.2.1.2.2.1.4
combustion equipment
3.2.2.1.2.1.2.2.1.5
mechanical equipment
3.2.2.1.2.1.2.2.1.6
contraband or other
AND
AND
AND
3.2.2.1.2.1.2.2.1.4.1
operating in vicinity
*
3.2.2.1.2.1.2.2.1.5.1
operating in vicinity
*
3.2.2.1.2.1.2.2.1.6.1
occurs in vicinity
*
3.2.2.1.2.1.2.2.1.4.2
causes excess heat
*
3.2.2.1.2.1.2.2.1.5.2
causes excess heat
*
3.2.2.1.2.1.2.2.1.6.2
causes excess heat
*
3.2.2.1.2.1.2.2.1.4.3
enough to ignite mixture
*
3.2.2.1.2.1.2.2.1.5.3
enough to ignite mixture
*
3.2.2.1.2.1.2.2.1.6.3
enough to ignite mixture
*
3.2.2.1.2.1.2.2.1.4.4
reaches mixture location
*
3.2.2.1.2.1.2.2.1.5.4
reaches mixture location
*
3.2.2.1.2.1.2.2.1.6.4
reaches mixture location
*


3.2.2.2
loose coal or accumulated coal dust in a developing area is raised to its ignition temp.
AND
3.2.2.2.1
loose coal or accumulated coal dust is present in the area *
3.2.2.2.2
coal is raised to its ignition temperature
OR
3.2.2.2.2.1
spark or flame
3.2.2.2.2.2
heat (not spark or flame)
p. 48
p. 49


3.2.2.2.2.1
spark or flame raises loose coal or accumulated coal dust in a developing area to its ignition temperature
AND
3.2.2.2.2.1.1
spark or flame comes in contact with coal
3.2.2.2.2.1.2
coal is raised to its ignition temperature by this spark/flame *
OR
3.2.2.2.2.1.1.1
cutting or drilling
3.2.2.2.2.1.1.2
shooting
3.2.2.2.2.1.1.3
electrical equipment
AND
AND
AND
3.2.2.2.2.1.1.1.1
performed in vicinity *
3.2.2.2.2.1.1.2.1
performed in vicinity *
3.2.2.2.2.1.1.3.1
operating in vicinity *
3.2.2.2.2.1.1.1.2
causes spark or flame *
3.2.2.2.2.1.1.2.2
causes spark or flame *
3.2.2.2.2.1.1.3.2
causes spark or flame *
3.2.2.2.2.1.1.1.3
comes in contact with coal *
3.2.2.2.2.1.1.2.3
comes in contact with coal *
3.2.2.2.2.1.1.3.3
comes in contact with coal *
3.2.2.2.2.1.1.4
combustion equipment
3.2.2.2.2.1.1.5
mechanical equipment
3.2.2.2.2.1.1.6
contraband or other
AND
AND
AND
3.2.2.2.2.1.1.4.1
operating in vicinity *
3.2.2.2.2.1.1.5.1
operating in vicinity *
3.2.2.2.2.1.1.6.1
occurs in vicinity *
3.2.2.2.2.1.1.4.2
causes spark or flame *
3.2.2.2.2.1.1.5.2
causes spark or flame *
3.2.2.2.2.1.1.6.2
causes spark or flame *
3.2.2.2.2.1.1.4.3
comes in contact with coal *
3.2.2.2.2.1.1.5.3
comes in contact with coal *
3.2.2.2.2.1.1.6.3
comes in contact with coal *



3.2.2.2.2.2
heat (without spark or flame) raises loose coal or accumulated coal dust in a developing area to its ignition temperature

AND

3.2.2.2.2.2.1
sufficient heat energy reaches location of coal

3.2.2.2.2.2.2
coal is raised to its ignition temperature by this heat *

OR

3.2.2.2.2.2.1.1
cutting or drilling

AND

3.2.2.2.2.2.1.1.1
performed in vicinity *

3.2.2.2.2.2.1.1.2
produces excess heat *

3.2.2.2.2.2.1.1.3
enough to ignite coal *

3.2.2.2.2.2.1.1.4
reaches coal location *

3.2.2.2.2.2.1.2
shooting

AND

3.2.2.2.2.2.1.2.1
performed in vicinity *

3.2.2.2.2.2.1.2.2
produces excess heat *

3.2.2.2.2.2.1.2.3
enough to ignite coal *

3.2.2.2.2.2.1.2.4
reaches coal location *

3.2.2.2.2.2.1.3
electrical equipment

AND

3.2.2.2.2.2.1.3.1
operating in vicinity *

3.2.2.2.2.2.1.3.2
produces excess heat *

3.2.2.2.2.2.1.3.3
enough to ignite coal *

3.2.2.2.2.2.1.3.4
reaches coal location *

3.2.2.2.2.2.1.4
combustion equipment

AND

3.2.2.2.2.2.1.4.1
operating in vicinity *

3.2.2.2.2.2.1.4.2
causes excess heat *

3.2.2.2.2.2.1.4.3
enough to ignite coal *

3.2.2.2.2.2.1.4.4
reaches coal location *

3.2.2.2.2.2.1.5
mechanical equipment

AND

3.2.2.2.2.2.1.5.1
operating in vicinity *

3.2.2.2.2.2.1.5.2
causes excess heat *

3.2.2.2.2.2.1.5.3
enough to ignite coal *

3.2.2.2.2.2.1.5.4
reaches coal location *

3.2.2.2.2.2.1.6
contraband or other

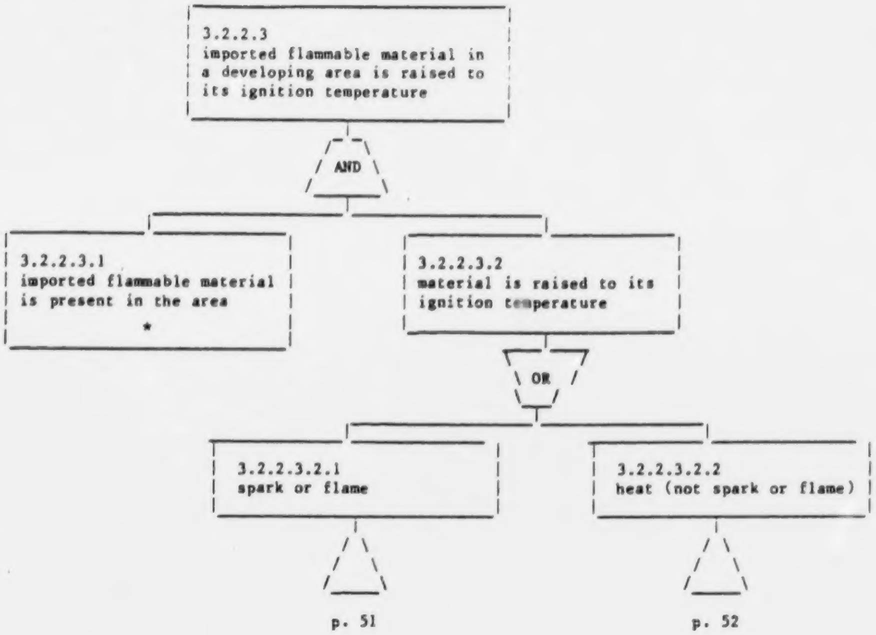
AND

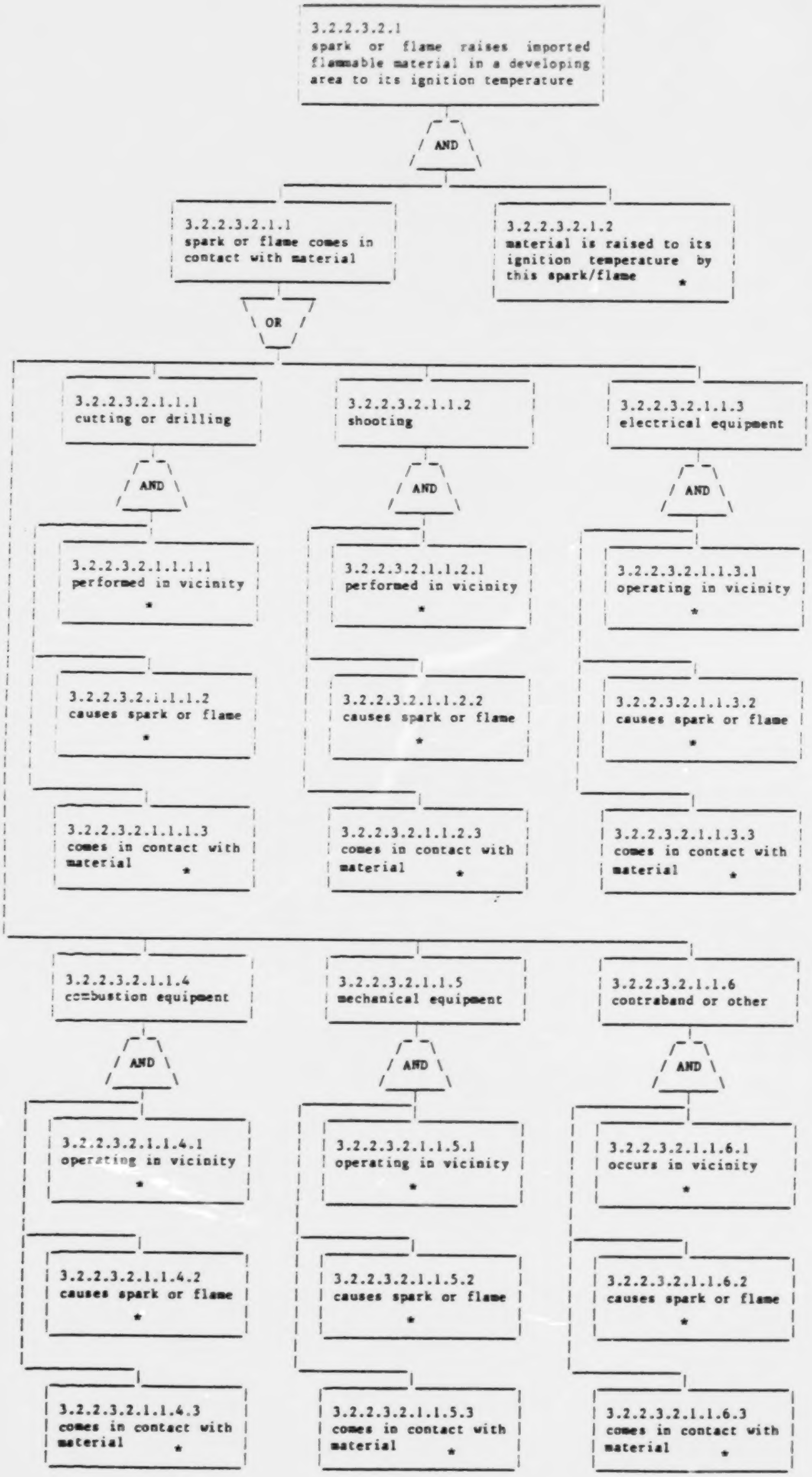
3.2.2.2.2.2.1.6.1
occurs in vicinity *

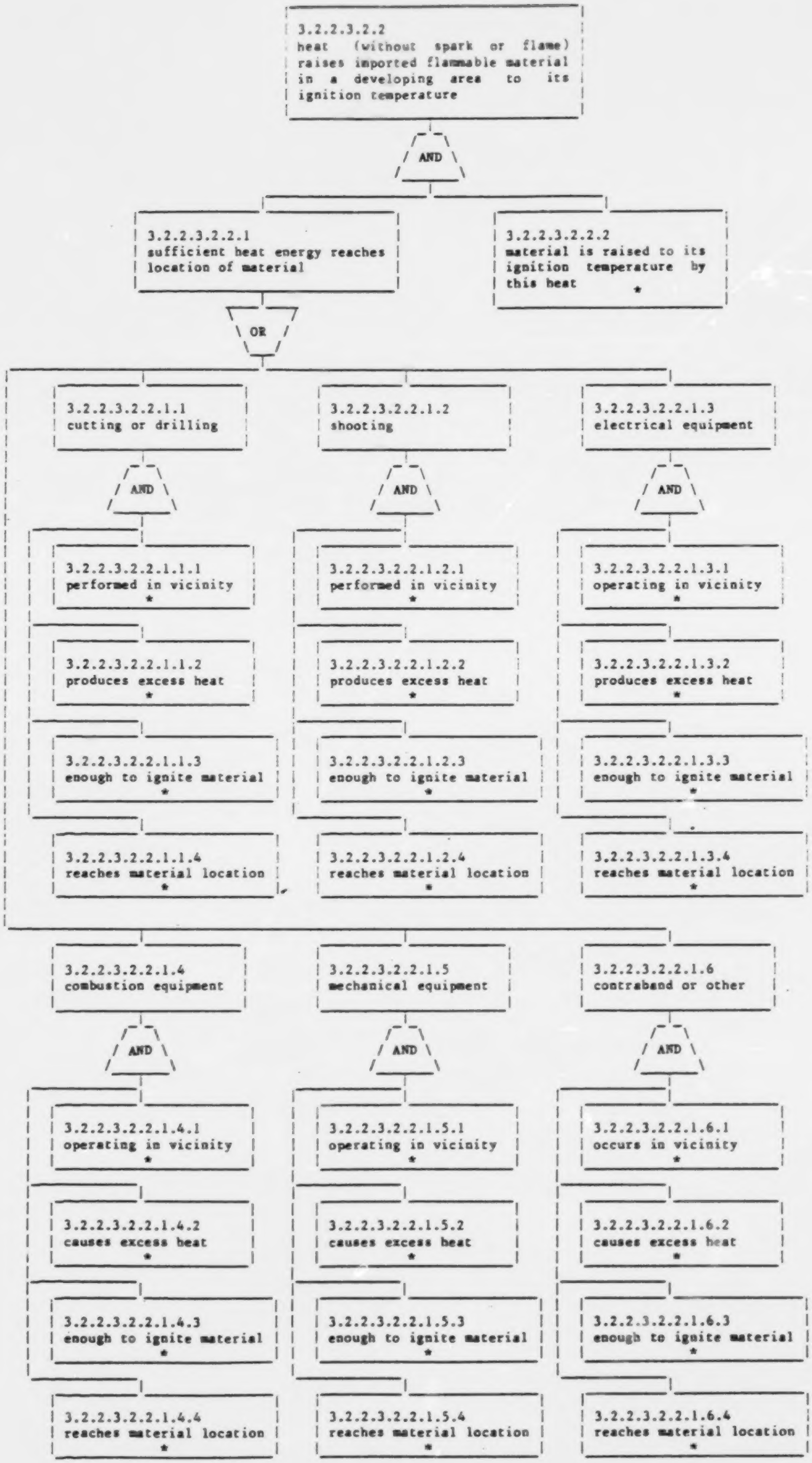
3.2.2.2.2.2.1.6.2
causes excess heat *

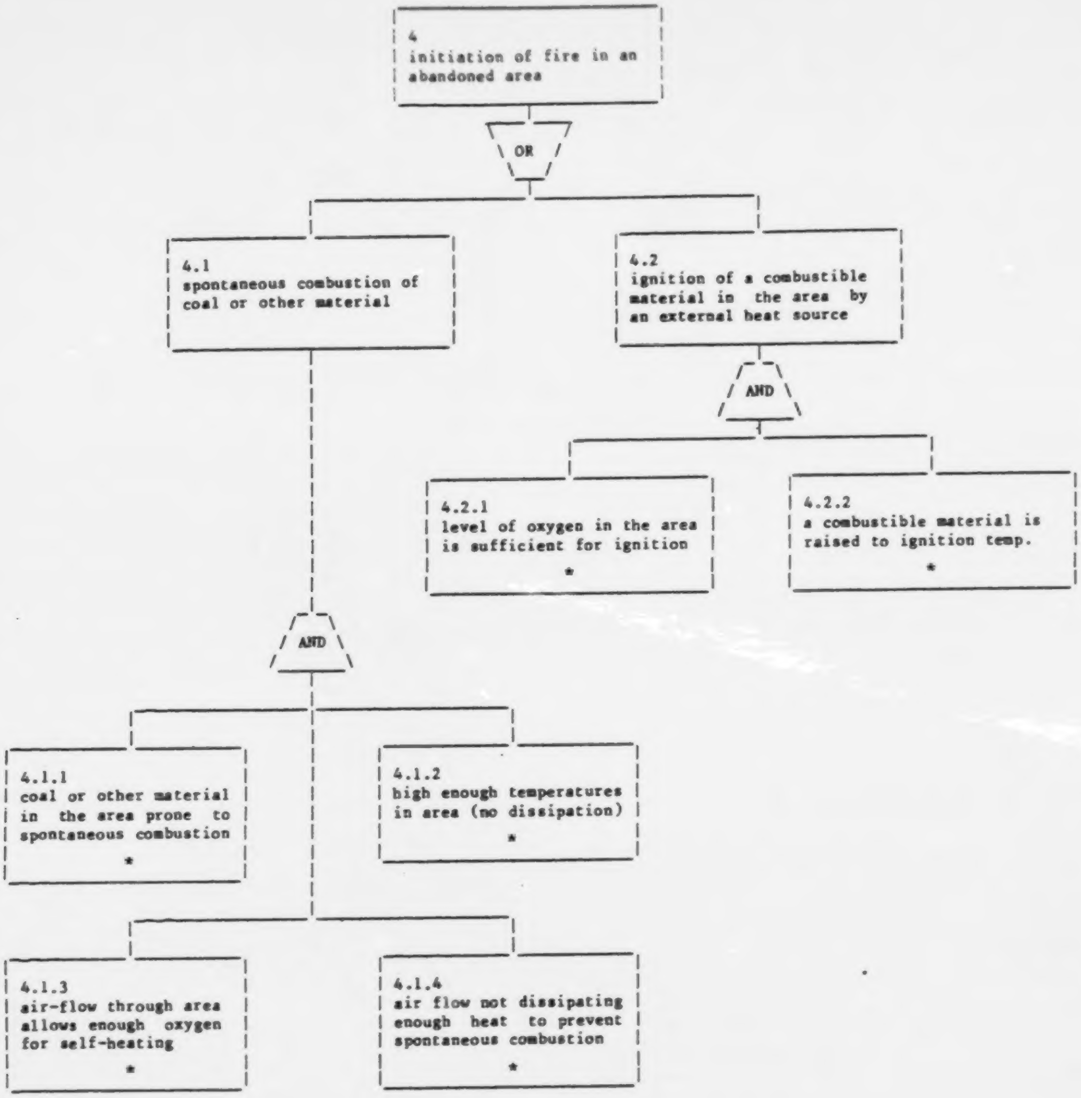
3.2.2.2.2.2.1.6.3
enough to ignite coal *

3.2.2.2.2.2.1.6.4
reaches coal location *


3.2.2.3
imported flammable material in a developing area is raised to its ignition temperature
AND
3.2.2.3.1
imported flammable material is present in the area
*
3.2.2.3.2
material is raised to its ignition temperature
OR
3.2.2.3.2.1
spark or flame
3.2.2.3.2.2
heat (not spark or flame)
p. 51
p. 52


3.2.2.3.2.1
spark or flame raises imported flammable material in a developing area to its ignition temperature
AND
3.2.2.3.2.1.1
spark or flame comes in contact with material
3.2.2.3.2.1.2
material is raised to its ignition temperature by this spark/flame *
OR
3.2.2.3.2.1.1.1
cutting or drilling
3.2.2.3.2.1.1.2
shooting
3.2.2.3.2.1.1.3
electrical equipment
AND
AND
AND
3.2.2.3.2.1.1.1.1
performed in vicinity *
3.2.2.3.2.1.1.2.1
performed in vicinity *
3.2.2.3.2.1.1.3.1
operating in vicinity *
3.2.2.3.2.1.1.1.2
causes spark or flame *
3.2.2.3.2.1.1.2.2
causes spark or flame *
3.2.2.3.2.1.1.3.2
causes spark or flame *
3.2.2.3.2.1.1.1.3
comes in contact with material *
3.2.2.3.2.1.1.2.3
comes in contact with material *
3.2.2.3.2.1.1.3.3
comes in contact with material *
3.2.2.3.2.1.1.4
combustion equipment
3.2.2.3.2.1.1.5
mechanical equipment
3.2.2.3.2.1.1.6
contraband or other
AND
AND
AND
3.2.2.3.2.1.1.4.1
operating in vicinity *
3.2.2.3.2.1.1.5.1
operating in vicinity *
3.2.2.3.2.1.1.6.1
occurs in vicinity *
3.2.2.3.2.1.1.4.2
causes spark or flame *
3.2.2.3.2.1.1.5.2
causes spark or flame *
3.2.2.3.2.1.1.6.2
causes spark or flame *
3.2.2.3.2.1.1.4.3
comes in contact with material *
3.2.2.3.2.1.1.5.3
comes in contact with material *
3.2.2.3.2.1.1.6.3
comes in contact with material *


3.2.2.3.2.2 heat (without spark or flame) raises imported flammable material in a developing area to its ignition temperature
AND
3.2.2.3.2.2.1 sufficient heat energy reaches location of material
3.2.2.3.2.2.2 material is raised to its ignition temperature by this heat *
OR
3.2.2.3.2.2.1.1 cutting or drilling
3.2.2.3.2.2.1.2 shooting
3.2.2.3.2.2.1.3 electrical equipment
AND
AND
AND
3.2.2.3.2.2.1.1.1 performed in vicinity *
3.2.2.3.2.2.1.2.1 performed in vicinity *
3.2.2.3.2.2.1.3.1 operating in vicinity *
3.2.2.3.2.2.1.1.2 produces excess heat *
3.2.2.3.2.2.1.2.2 produces excess heat *
3.2.2.3.2.2.1.3.2 produces excess heat *
3.2.2.3.2.2.1.1.3 enough to ignite material *
3.2.2.3.2.2.1.2.3 enough to ignite material *
3.2.2.3.2.2.1.3.3 enough to ignite material *
3.2.2.3.2.2.1.1.4 reaches material location *
3.2.2.3.2.2.1.2.4 reaches material location *
3.2.2.3.2.2.1.3.4 reaches material location *
3.2.2.3.2.2.1.4 combustion equipment
3.2.2.3.2.2.1.5 mechanical equipment
3.2.2.3.2.2.1.6 contraband or other
AND
AND
AND
3.2.2.3.2.2.1.4.1 operating in vicinity *
3.2.2.3.2.2.1.5.1 operating in vicinity *
3.2.2.3.2.2.1.6.1 occurs in vicinity *
3.2.2.3.2.2.1.4.2 causes excess heat *
3.2.2.3.2.2.1.5.2 causes excess heat *
3.2.2.3.2.2.1.6.2 causes excess heat *
3.2.2.3.2.2.1.4.3 enough to ignite material *
3.2.2.3.2.2.1.5.3 enough to ignite material *
3.2.2.3.2.2.1.6.3 enough to ignite material *
3.2.2.3.2.2.1.4.4 reaches material location *
3.2.2.3.2.2.1.5.4 reaches material location *
3.2.2.3.2.2.1.6.4 reaches material location *


4
initiation of fire in an abandoned area
OR
4.1
spontaneous combustion of coal or other material
4.2
ignition of a combustible material in the area by an external heat source
AND
4.2.1
level of oxygen in the area is sufficient for ignition
*
4.2.2
a combustible material is raised to ignition temp.
*
AND
4.1.1
coal or other material in the area prone to spontaneous combustion
*
4.1.2
high enough temperatures in area (no dissipation)
*
4.1.3
air-flow through area allows enough oxygen for self-heating
*
4.1.4
air flow not dissipating enough heat to prevent spontaneous combustion
*

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Fault Tree Model for the Initiation of Fire in an Active Coal Mine.

Each gate is listed with an output event description which is followed by a line naming the logical operator (AND or OR) which is followed by the input event descriptions.

Each event description is preceeded by a line containing an event number. This number is acually a series of digits and periods which indicate the position of the event in the tree. The top event is given the special identifier "TOP" and the input events for the first gate are numbered from 1 to the number of such inputs. Any other event is numbered with the number for the output event of the gate to which it is an input followed by a period and number from 1 to the number of inputs to that gate, depending on the order that the event is listed in.

The event number is marked in column 1 by a ">" for the output event of a gate and "-" for the gate input events.

An arrow (->) following the number for a gate input event indicates that the input is an intermediate event and will be further developed as the output event of a later gate.

An asterisk (*) following the number for a gate input event indicates a terminal or basic event, that is, an event which is not developed further in this fault tree.

Paragraphs of commentary information are indented, prefixed by a letter, and are referenced by the combination of the event number and the paragraph letter.

Many basic input events could be developed further, given greater detail into relevant mine operations and conditions. Alternatively, probabilities can be assigned directly to these events if the model was to quantified.

A description of the top of the tree is as follows:

> TOP
Initiation of fire in the mine given that there is no ongoing fire.

OR

- 1 ->
Initiation of fire in a working panel (given that there is no ongoing fire anywhere in the mine).

- 2 ->
Initiation of fire in a main tunnel or a permanent installation (given that there is no ongoing fire anywhere in the mine).

- 3 ->
Initiation of fire in a developing area (given that there is no ongoing fire anywhere in the mine).

- 4 ->
Initiation of fire in an abandoned area (given that there is no ongoing fire anywhere in the mine).

> 1
Initiation of fire in a working panel (given that there is no ongoing fire anywhere in the mine).

OR

- 1.1 ->
Initiation of fire in the face area of a working panel (given that there is no ongoing fire anywhere in the mine).

- 1.2 ->
Initiation of fire in an intake gate road of a working panel (given that there is no ongoing fire anywhere in the mine).

- 1.3 ->
Initiation of fire in a return gate road of a working panel (given that there is no ongoing fire anywhere in the mine).

- 1.4 ->
Initiation of fire in the gob area of a working panel (given that there is no ongoing fire anywhere in the mine).

> 1.1
Initiation of fire in the face area of a working panel (given that there is no ongoing fire anywhere in the mine).

OR

- 1.1.1 ->
Initiation of fire by spontaneous combustion of coal in the seam at the face of a working panel (given that there is no ongoing fire anywhere in the mine).

- 1.1.2 ->
Ignition of combustible material in the face area of a working panel (given that there is no ongoing fire anywhere in the mine).

> 1.1.1
Initiation of fire by spontaneous combustion of coal in the seam at the face of a working panel (given that there is no ongoing fire anywhere in the mine).

AND

- 1.1.1.1 *
Presence of coal prone to spontaneous combustion in the seam at the face of a working panel.

    a) Spontaneous combustion is caused when a combustible material in contact with oxygen undergoes oxidation reactions which produce heat (self-heating) and this heat builds up and reaches the ignition point of the material. Certain coals and some other materials, such as decomposing wood, are prone to spontaneous combustion.

- 1.1.1.2 *
Sufficiently high temperatures are maintained in the seam at the face of a working panel to produce spontaneous combustion if no heat were dissipated by air flow (given the type of coal in the seam and that there is no ongoing fire anywhere in the mine).

    a) The rate of oxidation reactions in a self-heating material depends on the chemical properties of the material, the amount of oxygen available, and the continuously maintained temperature of the material. Thus a high enough temperature when maintained continuously with no heat dissipation through air flow, will allow for self-heating to the point of ignition.

- 1.1.1.3 *
There is an air-flow through the seam at the face of a working panel permitting enough oxygen in contact with the coal to allow spontaneous combustion (given that there is no ongoing fire anywhere in the mine).

    a) This requires that the coal seam in this area is permeable so as to let air flow through bringing oxygen in contact with the coal. The source of this air might be the given mine area, other mine areas, other underground areas (such as an adjoining mine), or the surface (not in an underwater mine).

- 1.1.1.4 *
The flow of air through the seam at the face of a working panel does not dissipate enough heat to prevent spontaneous combustion (given that the temperature maintained in the seam is high enough in the absence of such dissipation to produce such a spontaneous combustion, that there is enough air-flow in the seam to provide the required oxygen and that there is no ongoing fire anywhere in the mine).

    a) The higher the rate of air flow through the area, the higher the ambient temperature must be to maintain the reaction in spite of heat dissipation.

> 1.1.2
Ignition of a combustible material in the face area of a working panel (given that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.1 *
Level of oxygen in the air in the face area of a working panel is sufficient to allow combustion (given that there is no ongoing fire anywhere in the mine).

  a) Thiswill generally be the case in any non-abandoned mine area.

- 1.1.2.2 ->
A combustible material in the face area of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 1.1.2.2
A combustible material in the face area of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.1 ->
Explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.2 ->
Loose coal or accumulated coal dust in the face area of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.3 ->
An imported flammable material in the face area of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 1.1.2.2.1
Explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.1.1 *
Presence of an explosive mixture of methane and/or airborne coal dust in the face area of a working panel (given that the level of oxygen in the area is sufficiently high for combustion).

  a) Methane is released from coal in the seam as it is mined and also coal on conveyors, etc. Its concentration in the air at the face depends mainly on the gas content of the coal, the rate at which the coal is being extracted, and the rate at which the gas is removed from the area by air flow. An effort is usually made to control the ventilation system so that the air flow at the face will be sufficient to keep the methane levels within a level judged to be safe. Other factors can also contribute such as methane released from the gob or methane in the intake air from a source upstream.

  b) Airborne coal-dust is produced in the mining process but may also be stirred up from accumulations on the floor and other surfaces in the face area by excessive air flow or other disturbances. Measures are often taken to reduce of airborne coal dust, including the spraying of water on the coal face where the shearer is operating to lay the dust and the spreading of inert material (such as limestone dust) on surfaces over the coal dust.

c) The concentration of methane in the air must be within limits of 5 and 15 percent in order to be ignitable. There must be enough gas to provide fuel for a sustained explosion but there must also be a sufficient level of oxygen in the air for combustion. The minimum dust content required for an explosion in undefined. In general, the ignitability of any mixture of methane, airborne coal dust, and oxygen is related in a complex manner to the levels of all three components.

- 1.1.2.2.1.2 ->
  Explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.1.2.2.1.2
Explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

OR (exclusive)

- 1.1.2.2.1.2.1 ->
  Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.1.2.2 ->
  Mine is evacuated and explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.1.2.2.1.2.1
Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.1.2.1.1 *
  Mine is not evacuated (given that an explosive mixture of methane and/or airborne coal dust is present in the face area of a working panel).

  a) This event is the logical negative of 1.1.2.2.1.2.2.1

- 1.1.2.2.1.2.1.2 ->
  Explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area, that the mine is not evacuated and that there is no ongoing fire anywhere in the mine).

> 1.1.2.2.1.2.2
Mine is evacuated and explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.1.2.2.1 *
  Mine is evacuated (given that an explosive mixture of methane and/or coal-dust is present in the face area of a working panel).

  a) Modern mines employ an automatic methane detection system at the top end of face (where the highest methane levels are likely to occur) and as well, frequent manual tests are done at this and other points with hand-held methanometers. When methane levels are above a certain standard level (1.25%), mining operations are curtailed and the panel evacuated until the methane level is safe. This will have the effect of greatly reducing the probability of a spark or flame being produced as the result of mining operations while methane levels are in the ignitable range. One problem with these systems is that many factors besides methane concentration can contribute to an explosion and, although in some cases there may be testing done for some of these other factors, it is usually possible that methane levels within the prescribed limits for saftey may in fact be hazardous. Another limitation is that both automatic and manual tests only cover certain points in the area so that high concentrations which may exist at other points, such as in the methane pockets described above, may go undetected. Thus, if the detectors are operational, if they are accurate in reporting the levels of methane and other air-related hazards, if those levels are correctly sensed by the automatic systems or judged by supervisors to be hazardous, and if safety procedures are effective in halting mining operations and evacuating the section when such hazardous conditions are recognized, then this event is true.

  b) This event is the logical negative of 1.1.2.2.1.2.1.1.

- 1.1.2.2.1.2.2.2 *
  Explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area, that mine is evacuated and that there is no ongoing fire anywhere in the mine).

  a) This event represents the possibility of a methane/coal dust explosion occurring when mining has ceased, the section evacuated, and all electrical systems shut down.

> 1.1.2.2.1.2.1.2
Explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.1.2.1.2.1 ->
  A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in the face area of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.1.2.1.2.2 ->
  Heat (without sparks or flame) raises an explosive mixture of methane and/or airborne coal dust in the face area of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

> 1.1.2.2.1.2.1.2.1
A spark or open flame raises an explosive mixture of methane and/or

airborne coal dust in the face area of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.1.2.1.2.1.1 ->
A spark or open flame reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.1.2.1.2.1.2 *
An explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point by a spark or open flame (given that a point in the area where such a mixture exists has been reached by a spark or open flame).

    a) The ignition points for methane and airborne coal dust mixtures are relatively low so that any spark or open flame reaching a point with an ignitable mixture of either or both of these is likely to cause an explosion.

> 1.1.2.2.1.2.1.2.2
Heat (without spraks or flame) raises an explosive mixture of methane and/or airborne coal dust in the face area of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.1.2.1.2.2.1 ->
Enough heat energy (without sparks or flame) reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.1.2.1.2.2.2 *
An explosive mixture of methane and/or airborne coal dust in the face area of a working panel is raised to its ignition point by heat without sparks or flame (given that enough heat energy reaches a point in the area where such a mixture exists).

    a) Because methane is usually carried out of the area fairly quickly with the normal air flow and because airborne coal dust tends to settle out, there is less chance for build up of heat to the ignition point. Therefore, to cause an explosion without a flame or spark would require unusually high temperatures to be generated at a point where there was an explosive mixture.

> 1.1.2.2.1.2.1.2.1.1
A spark or open flame reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.1.2.1.2.1.1.1 ->
Coal cutting, rock cutting or drilling operations cause a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.1.1.2 ->
  Shooting operations cause a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.1.1.3 ->
  Operation of electrical equipment causes a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.1.1.4 ->
  Operation of combustion equipment causes a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.1.1.5 ->
  Operation of mechanical equipment causes a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

> 1.1.2.2.1.2.1.2.2.1
Enough heat energy (without sparks or flame) reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.1.2.1.2.2.1.1 ->
  Coal cutting, rock cutting, or drilling operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.2.1.2 ->
  Shooting operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.2.1.3 ->
  Operation of electrical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.2.1.4 ->
  Operation of combustion equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.2.1.5 ->

Operation of mechanical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.1.2.2.1.2.1.2.2.1.6 ->
Use of contraband or other fire hazard causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

> 1.1.2.2.1.2.1.2.1.1.1
Coal cutting, rock cutting or drilling operations cause a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.1.1.1.1 *
Coal cutting, rock cutting or drilling operations are being performed in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

  a) Coal cutting is done with a "shearer" which is drawn along the coal face from the intake tunnel (lower) end, from the point of the inside tunnel wall, leaving the area to cut by the roadway cutter, up to the return tunnel (upper) end, right to the far tunnel wall. It operates intermittently during all active mining periods, being run up the wall, stopped, reset and run down the wall in the other direction.

  b) A roadway cutter is used in the intake tunnels and may be cutting through coal or rock in the vicinity of the face. It can be operating any time during active mining.

  c) Drilling (with electric hand drills) is done at the top end of the face in preparation for shooting (blasting) to remove rock and coal left by the shearer so that the return tunnel may be developed. Drilling/shooting may also be occasionally done other areas to remove rock intrusions, etc.

  d) In this branch it is pre-supposed that an explosive mixture of methane and coal-dust is present in the area and, despite the systems for detection, alarm, and automatic shut-down in the event of such hazards, the mine has not been evacuated (see comment 1.1.2.2.1.2.2.2.1.a). This does not have to be considered where this event appears in other branches not dealing with methane hazards since the presence of other flammable materials does not generally warrant an evacuation of the mine.

- 1.1.2.2.1.2.1.2.1.1.1.2 *
Coal cutting, rock cutting or drilling operations cause a spark or open flame in the vicinity of the face area of a working panel (given that such operations are being performed in the vicinity).

  a) These machines are all used for cutting into coal and/or rock and can produce heat, sparks and flame when they are cutting because incendive friction between the cutting bits and the material being cut. This is more likely to happen with certain types of rock, such as pyritic or siliceous sandstone, than with coal. Often rock strata can intrude into the coal seam from above or below and into the path of the shearer. The use of water sprays on the shearer directed at the cutting point may reduce the amount of heat and number of sparks produced.

- 1.1.2.2.1.2.1.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of the face area of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such operations in the vicinity).

    a) A spark or flame may travel some distance from where it is produced. Therefore the likelihood that a spark or flame will reach a nearby combustible material (or point at which an ignitable air mixture exists) must be considered here. This will depend mainly on the proximity of the combustible material to the point where the sparks or flames are produced and the existence of a clear path between the two. There is also the small possibility that a spark will fall on a moving surface and will be carried, still burning, to a point where it comes in contact with a combustible material. In fact, the spark or flame does not necessarily have to originate in the mine area being considered, but may be produced in an adjoining area and travel into the given area (hence the use of the phrase "in the vicinity of the area").

    b) Concentrations of methane and airborne coal dust will tend to vary considerably from point to point within an area. In particular, certain points, such as the top of the wall or in cavities in the roof, may be prone to having pockets of high concentration methane.

> 1.1.2.2.1.2.1.2.1.1.2
Shooting operations cause a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.1.1.2.1 *
Shooting operations are being performed in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

    a) Shooting (blasting) is done at the top end of the face in the course of developing the return tunnel and occasionally at other points in the face area when rock must be removed.

    b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d. The probability of this event is considerably lower than in other branches not concerning methane/coal dust mixtures. A manual test for methane levels is conducted immediately before every shot, making it highly unlikely, but not impossible, that shooting will be carried out in the presence of a dangerous methane/coal dust mixture. Thus, this event requires that the test not be done, or that the equipment malfunctions or was misused or that the explosive mixture does not exist within range of the test equipment.

- 1.1.2.2.1.2.1.2.1.1.2.2 *
Shooting operations cause a spark or open flame in the vicinity of the face area of a working panel (given that such operations are being performed in the vicinity).

    a) Normally the explosives are formulated and placed in such a way as to prevent sparks, flames or excessive heat being produced. Use of sub-standard explosives, setting an incorrect charge or drilling a charge hole through the other side, however, could result in high temperatures or spark and flame ejection.

- 1.1.2.2.1.2.1.2.1.1.2.3 *
Spark or open flame caused by shooting operations in the vicinity of the face area of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given

that such a mixture is present in the area and that a spark or open flame has been produced by such operations in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.1.1.1.3.a & b.

b) Again it must be considered here that the methane/coal dust levels are given to be high and that they are tested before each shot. As explained in 1.1.2.2.1.2.1.2.1.1.2.1.a, The test may have failed because the high methane levels did not exist within the measuring radius of the test equipmet. In this case the explosive mixture is also likely to be too far away to be afffected

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> 1.1.2.2.1.2.1.2.1.1.3
Operation of electrical equipment causes a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

a) Electrical equipment used in the vicinity of an active face includes drive motors for the shearer drum, shearer haulage, armoured face conveyor, and road cutter as well as lighting and electric tools, etc.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.1.2.2.1.2.1.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

a) Electrical equipment can create spark or flame ("arcing") when any live conductors are brought into contact. All electrical equipment used in the mine is designed to prevent arcing or to cool any sparks before they reach the atmosphere. It sometimes occurs, however, because of inadequate design or fault of the equipment or human error or accident. Examples of this are: worn insulation exposing a live conductor; a short circuit which causes a wire to heat up to the point where the insulation and/or the wire itself burns through; an access door being left open exposing switch contacts or a motor using a commutator or a starter; cables which are connected or disconnected while live, a live cable being accidentally cut or damaged so as to expose the conductor; the accidental breaking of a light bulb. Note that this event could occur through accident, equipment malfunction, or possibly in the course of normal use. This does not include anything covered by event 1.1.2.2.1.2.1.2.1.1.1.2.

- 1.1.2.2.1.2.1.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the face area of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.1.1.1.3.a & b.

> 1.1.2.2.1.2.1.2.1.1.4
Operation of combustion equipment causes a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been

evacuated).

AND

- 1.1.2.2.1.2.1.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

  a) Combustion equipment refers mainly to diesel locomotives used for hauling mine cars but includes any equipment which uses internal combustion engines, welding equipment, or in any way employs combustion. Combustion equipment is not normally used in areas where the level of methane may be high such as at or near the face area and in the return air tunnels.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.1.2.2.1.2.1.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

  a) Normally all equipment in the mine using combustion engines is designed not to allow a spark, open flame, or high heat surfaces in the environment. Problems could occur, however, because of inadequate design, mechanical fault, human error, or accident. Examples of problems which could cause a spark or flame to escape are an access door being left open, a hole in the casing, or a severe backfire. Note that this event could occur through accident, equipment malfunction, or possibly in the course of normal use. Welding should not provide a significant hazard because careful testing for methane would be performed before and possibly during any welding operations in the mine. This event does not include anything covered by event 1.1.2.2.1.2.1.2.1.1.1.2.

- 1.1.2.2.1.2.1.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of the face area of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comments 1.1.2.2.1.2.1.2.1.1.1.3.a & b.

> 1.1.2.2.1.2.1.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

  a) Mechanical equipment includes anything with moving parts. In the vicinity of the face area this would include drive and control assemblies for the shearer drums, shearer haulage, armoured face conveyor, road cutter, etc. as well as the hydraulic roof supports, miscellaneous tools, etc.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.1.2.2.1.2.1.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

  a) Certain materials when struck together can cause a spark or flame because of incendive friction. Precautions are normally taken to prevent the use of such materials in the mine. Such occurrences, however, may occasionally take place. Note that this event could occur through accident, equipment malfunction, or possibly in the course of normal use. This event does not include anything covered by event 1.1.2.2.1.2.1.2.1.1.1.2.

- 1.1.2.2.1.2.1.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of the face area of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.1.1.1.3.a & b.

> 1.1.2.2.1.2.1.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which reaches a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

a) Smoking and in fact any possession of materials for creating an open flame is strictly banned, so this should rarely be a problem.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.1.2.2.1.2.1.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the face area of a working panel (given that such use or hazard occurs in the vicinity).

a) This event might occur if a match was lit in the area or a lit cigarette brought into the area.

- 1.1.2.2.1.2.1.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.1.1.1.3.a & b.

b) There is a higher probability in the case of contraband that the burning or heat producing object may be carried by a human to a point where it can come in contact with a combustible material.

> 1.1.2.2.1.2.1.2.2.1.1
Coal cutting, rock cutting or drilling operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operations are being performed in the vicinity of the face area of a working panel (given that the

mine has not been evacuated).

a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.1.1.

- 1.1.2.2.1.2.1.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operations in the vicinity of the face area of a working panel cause excess heat energy to be produced (given that such operations are being performed in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a.

  b) Many objects and processes in the mine produce some amount of excess heat energy, including most operating equipment and even the miner's bodies. Of course most such heat sources do not produce enough heat to be a hazard. At a certain level of heat production, there is a danger that the temperature of some combustible material will be raised to its ignition point. The actual transfer of this heat energy to a combustible material and the raising of the temperature of that material to the ignition point is a complex process dependant on many factors. This process is dealt with over several events at various levels of the model. For this event some critical temperature, judged to be an unsafe level of heat production should be chosen that the probability of that level being achieved be used.

- 1.1.2.2.1.2.1.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of the face area of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.2.a. Similarly the amount of heat energy which could, potentially, raise an explosive gas/dust mixture to its ignition temp, is relatively low.

  b) For this event it should be assumed that all heat energy produced is transferred to and retained by the combustible material. The processes of transfer and dissipation are dealt with elsewhere. Thus this event the production of enough heat energy to raise the temperature of the combustible material from the average ambient temperature to the ignition point.

- 1.1.2.2.1.2.1.2.2.1.1.4 *
Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of the face area of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

  a) Heat can travel from where it is produced by radiation, conduction, or convection. Radiant heat is diffused quickly over distance. Thus transfer of heat usually occurs by conduction or convection. In most cases the combustible material will have to be in contact with the heat producing object. However, metal is a good conductor of heat while coal, wood, and air are relatively poor. Thus the amount of heat energy reaching a nearby combustible material (or point at which an ignitable air mixture exists) from where it is produced must be considered here. This will depend mainly on the distance from the source of heat to the combustible material but also on the intervening material and its ability to conduct heat and such factors as air flow which might help dissipate the heat. In fact, the heat does not necessarily have to originate in the mine area being considered, but may be produced in an adjoining area and travel into the given area (hence the use of the phrase "in the vicinity of the area"). Note this event does include the transmission of heat by sparks and flame as these are covered elsewhere.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.3.b.

> 1.1.2.2.1.2.1.2.2.1.2
Shooting operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.2.1.2.1 *
Shooting operations are being performed in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

a) This event is identical to 1.1.2.2.1.2.1.2.1.1.2.1

- 1.1.2.2.1.2.1.2.2.1.2.2 *
Shooting operations in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such operations are being performed in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

b) See comment 1.1.2.2.1.2.1.2.2.1.1.2.b.

- 1.1.2.2.1.2.1.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the face area of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.1.2.2.1.2.1.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the face area of a working panel reaches a point in the face area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.3.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.2.3.b.

> 1.1.2.2.1.2.1.2.2.1.3
Operation of electrical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

a) This event is identical to 1.1.2.2.1.2.1.2.1.1.3.1

- 1.1.2.2.1.2.1.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

a) All electrical equipment generates some heat but that which is used in the mine is designed so as not to produce enough heat to ignite any flammable materials or gas. Faults or accidents, however, could create such problems because of short circuiting, or overloading in conjunction with the absence of or non-functioning of a circuit breaker or overload detector, or, perhaps, due to the non-functioning of a cooling system. Note that this event could occur through accident, equipment malfunction, or possibly in the course of normal use. This does not include anything covered in event 1.1.2.2.1.2.1.2.2.1.1.2.

b) See comment 1.1.2.2.1.2.1.2.2.1.1.2.b.

- 1.1.2.2.1.2.1.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the face area of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.1.2.2.1.2.1.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of the face area of a working panel reaches a point in the face area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.3.b.

> 1.1.2.2.1.2.1.2.2.1.4
Operation of combustion equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

a) This event is identical to 1.1.2.2.1.2.1.2.1.1.4.1

- 1.1.2.2.1.2.1.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.4.2. Eamples of problems which could cause a combustion engine to overheat are inadequate lubricating oil, incorrect fuel mixture, overloading, inadequate functioning of the cooling system, etc. Note that this event could occur through accident, equipment malfunction, or possibly in the course of normal use. This event does not include anything covered by 1.1.2.2.1.2.1.2.2.1.1.2.

b) See comment 1.1.2.2.1.2.1.2.2.1.1.2.b.

- 1.1.2.2.1.2.1.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the face area of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.1.2.2.1.2.1.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the face area of a working panel reaches a point in the face area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.3.b.

> 1.1.2.2.1.2.1.2.2.1.5
Operation of mechanical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

  a) This event is identical to 1.1.2.2.1.2.1.2.1.1.5.1

- 1.1.2.2.1.2.1.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

  a) Many types of mechanical equipment with moving parts can generate heat because of friction. Normally, such friction is controlled (by lubrication, etc.) so as not to produce enough heat to ignite any flammable material normally found in the mine. Equipment faults or lack of maintenance, however, could create such problems because of inadequate lubrication, worn bearings, excessive load, parts not meant to rub together doing so, etc. Note that this event could occur through accident, equipment malfunction, or possibly in the course of normal use. This event does not include anything covered in 1.1.2.2.1.2.1.2.2.1.1.2.

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.2.b.

- 1.1.2.2.1.2.1.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the face area of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.1.2.2.1.2.1.2.2.1.5.4 *
Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of the face area of a working panel reaches a point in the face area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.3.b.

> 1.1.2.2.1.2.1.2.2.1.6
Use of contraband or other fire hazard causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.1.2.2.1.2.1.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the face area of a working panel (given that the mine has not been evacuated).

    a) This event is identical to 1.1.2.2.1.2.1.2.1.1.6.1

- 1.1.2.2.1.2.1.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such use or hazard occurs in the vicinity).

    a) This might occur under much the same circumstances as 1.1.2.2.1.2.1.2.1.1.6.2.

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.2.b.

- 1.1.2.2.1.2.1.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.1.2.2.1.2.1.2.2.1.6.4 *
Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 1.1.2.2.1.2.1.2.1.1.1.3.b.

    c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.1.2.2.2
Loose coal or accumulated coal dust in the face area of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.2.1 *
Presence of loose coal or accumulated coal dust in the face area of a working panel.

    a) This includes mined coal on the conveyors or in hoppers, spilled coal, and coal dust ("fines") that have accumulated on the floor and other surfaces.

- 1.1.2.2.2.2 ->
Loose coal or accumulated coal dust in the face area of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.1.2.2.2.2
Loose coal or accumulated coal dust in the face area of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.2.2.1 ->
A spark or open flame raises loose coal or accumulated coal dust in the face area of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.2.2.2 ->
Heat (without flame or spark) raises loose coal or accumulated coal dust in the face area of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.2.2.3 *
Spontaneous combustion of loose coal or accumulated coal dust in the face area of a working panel (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

  a) The likelihood of spontaneous combustion of a given material, given its presence and an adequate level of oxygen in the air, will depend on the chemical properties of the material (how easily oxidizable it is), the amount of material and its fineness, and the ambient temperature maintained in the area. This event could be developed much like event 1.1.1. The branch for the requirement of oxygen in contact with the combustible material, however, would be somewhat different as it is given by the proportion of oxygen the air at the given area.

> 1.1.2.2.2.2.1
A spark or open flame raises loose coal or accumulated coal dust in the face area of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.2.2.1.1 ->
A spark or open flame comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.2.2.1.2 *
Loose coal or accumulated coal dust in the face area of a working panel is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

  a) The likelihood of a spark or flame igniting a combustible material, given that such a spark or flame has been produced, that the material is present and that the level of oxygen is sufficient, will depend on the the spark or flame coming in contact with the material (covered in the other branch) and on the flammability of the material. Factors affecting this are its ignition temperature, its physical state given the ambient temperature, the amount of surface area exposed to oxygen, and the ability of air-flow around the material or other factors to prevent the ignition.

  b) For loose coal and accumulated coal dust, a major concern is the fineness of the coal. The smaller the pieces, or the finer the dust, the easier it is to ignite.

> 1.1.2.2.2.2.2
Heat (without sparks or flame) raises loose coal or accumulated coal dust in the face area of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.2.2.2.1 ->
Enough heat energy (without sparks or flame) reaches a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that the mine has not been evacuated).

- 1.1.2.2.2.2.2.2 *
Loose coal or accumulated coal dust in the face area of a working panel is raised to its ignition point by heat energy without sparks or flame (given that enough heat energy reaches a point in the area where such material exists).

a) The likelihood of heat alone igniting a combustible material, given that the material is present and that the level of oxygen is sufficient, depends mainly on enough heat energy reaching the material and being absorbed and retained so that the temperature of the material rises to the ignition point. Assuming that enough heat energy is reaching the point where the material exists to raise its temperature to the ignition point (dealt with in the other branch) this event covers the absorption and retention of enough of that heat by the material to raise its temperature to its ignition point. Factors which affect this are the proportion of surface of the material exposed to air, the physical state of the combustible material, its thermal characteristics (how it easily absorbs and retains heat) and the ability of air-flow around the material or other factors to dissipate the heat.

b) See comment 1.1.2.2.2.2.1.2.b.

> 1.1.2.2.2.2.1.1
A spark or open flame comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.2.2.1.1.1 ->
Coal cutting, rock cutting, or drilling operations cause a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.2.2.1.1.2 ->
Shooting operations cause a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.2.2.1.1.3 ->
Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.2.2.1.1.4 ->
Operation of combustion equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.2.2.1.1.5 ->
  Operation of mechanical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.2.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

> 1.1.2.2.2.2.2.1
Enough heat energy (without sparks or flame) reaches a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

OR

- 1.1.2.2.2.2.2.1.1 ->
  Coal cutting, rock cutting, or drilling operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.2.2.2.1.2 ->
  Shooting operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.2.2.2.1.3 ->
  Operation of electrical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.2.2.2.1.4 ->
  Operation of combustion equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.2.2.2.1.5 ->
  Operation of mechanical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.2.2.2.1.6 ->
  Use of contraband or other fire hazard causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

> 1.1.2.2.2.2.1.1.1
Coal cutting, rock cutting, or drilling operations cause a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.2.2.1.1.1.1 *
  Coal cutting, rock cutting, or drilling operations are being performed in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.1.1.

- 1.1.2.2.2.2.1.1.1.2 *
Coal cutting, rock cutting, or drilling operations cause a spark or open flame in the vicinity of the face area of a working panel (given that such operations are being performed in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.1.2.

- 1.1.2.2.2.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting, or drilling operations in the vicinity of the face area of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.2.2.1.1.2
Shooting operations cause a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.2.2.1.1.2.1 *
Shooting operations are being performed in the vicinity of the face area of a working panel.

    a) See comments 1.1.2.2.1.2.1.2.1.1.2.1.a & b. This branch does not assume high methane levels, so the probability of a shot is higher.

- 1.1.2.2.2.2.1.1.2.2 *
Shooting operations cause a spark or open flame in the vicinity of the face area of a working panel (given that such operations are being performed in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.2.2.

- 1.1.2.2.2.2.1.1.2.3 *
Spark or open flame caused by shooting operations in the vicinity of the face area of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.2.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.2.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.3.1.

- 1.1.2.2.2.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.3.2.

- 1.1.2.2.2.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the face area of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such

material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.2.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.2.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of the face area of a working panel.

  a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.4.1.

- 1.1.2.2.2.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.4.2.

- 1.1.2.2.2.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of the face area of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.2.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.2.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of the face area of a working panel.

  a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.5.1.

- 1.1.2.2.2.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.5.2.

- 1.1.2.2.2.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of the face area of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.2.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.2.2.1.1.6.1 *
  Use of contraband or other fire hazard occurs in the vicinity of the face area of a working panel.

  a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.6.1.

- 1.1.2.2.2.2.1.1.6.2 *
  Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the face area of a working panel (given that such use or hazard occurs in the vicinity).

  a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.6.2.

- 1.1.2.2.2.2.1.1.6.3 *
  Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.1.2.2.2.2.2.1.1
Coal cutting, rock cutting, or drilling operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.2.2.2.1.1.1 *
  Coal cutting, rock cutting, or drilling operations are being performed in the vicinity of the face area of a working panel.

  a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.1.1.

- 1.1.2.2.2.2.2.1.1.2 *
  Coal cutting, rock cutting, or drilling operations in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such operations are being performed in the vicinity).

  a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.1.2.

- 1.1.2.2.2.2.2.1.1.3 *
  Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting, or drilling operations in the vicinity of the face area of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

  a) The ignition temperature of coal is relatively high compared to that of methane and most imported flammable materials including wood.

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.2.2.2.1.1.4 *
  Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting, or drilling operations in the vicinity of the face area of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.2.2.2.1.2
Shooting operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.2.2.2.1.2.1 *
  Shooting operations are being performed in the vicinity of the face area of a working panel.

  a) This event is identical to event 1.1.2.2.2.2.1.1.2.1.

- 1.1.2.2.2.2.2.1.2.2 *
  Shooting operations in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such operations are being performed in the vicinity).

  a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.2.2.

- 1.1.2.2.2.2.2.1.2.3 *
  Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the face area of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.2.2.2.1.2.4 *
  Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the face area of a working panel reaches a point in the face area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.2.2.2.1.3
Operation of electrical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.2.2.2.1.3.1 *
  Electrical equipment is operating in the vicinity of the face area of a working panel.

  a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.3.1.

- 1.1.2.2.2.2.2.1.3.2 *
  Operation of electrical equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.3.2.

- 1.1.2.2.2.2.2.1.3.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the face area of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.2.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of the face area of a working panel reaches a point in the face area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.2.2.2.1.4
Operation of combustion equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.2.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of the face area of a working panel.

a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.4.1.

- 1.1.2.2.2.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.4.2.

- 1.1.2.2.2.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the face area of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.2.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the face area of a working panel reaches a point in the face area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.2.2.2.1.5
Operation of mechanical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.2.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of the face area of a working panel.

a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.5.1.

- 1.1.2.2.2.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.5.2.

- 1.1.2.2.2.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the face area of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.2.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.2.2.2.1.5.4 *
Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of the face area of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.2.2.2.1.6
Use of contraband or other fire hazard causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.2.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.6.1.

- 1.1.2.2.2.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such use or hazard occurs in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.6.2.

- 1.1.2.2.2.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.2.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.2.2.2.1.6.4 *
Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

    b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.1.2.2.3
An imported flammable material in the face area of a working panel is raised to its ignition point (given that the level of oxygen in the

area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.3.1 *
  Presence of an imported flammable material in structures, in equipment, or lying loose at the face area of a working panel.

  a) Flammable materials in structures could include untreated wood used for roof supports or flammable foams used to fill cavities or make the gob area air-tight.

  b) Flammable materials in equipment could include lubricating oil in machinery, fuel in combustion engines (not likely to be present at the face), insulation on electrical wiring, rope used for haulages and for pull cords, etc.

  c) Loose flammable materials could include wood stored for construction purposes, stored explosives, stored lubricating oils or fuels, clothing, paper, etc.

- 1.1.2.2.3.2 ->
  An imported flammable material in the face area of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.1.2.2.3.2
An imported flammable material in the face area of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.3.2.1 ->
  A spark or open flame raises an imported flammable material in the face area of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.3.2.2 ->
  Heat (without sparks or flame) raises an imported flammable material in the face area of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.3.2.3 *
  Spontaneous combustion of an imported flammable material in the face area of a working panel (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.2.2.2.2.3.a.

> 1.1.2.2.3.2.1
A spark or open flame raises an imported flammable material in the face area of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.3.2.1.1 ->
  A spark or open flame comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.3.2.1.2 *
  An imported flammable material in the face area of a working panel is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

a) See comment 1.1.2.2.2.2.1.2.a.

b) The ignition points, locations, and surroundings of various imported flammable materials varies quite a bit depending on the nature of the particular material in question. Therefore, the susceptibility to ignition will be hard to estimate for this group as a whole. In a quantitative model, this branch could be split into several depending on range of susceptibility.

> 1.1.2.2.3.2.2
Heat (without sparks or flame) raises an imported flammable material in the face area of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.1.2.2.3.2.2.1 ->
Enough heat energy (without sparks or flame) reaches a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.1.2.2.3.2.2.2 *
An imported flammable material in the face area of a working panel is raised to its ignition point by heat without sparks or flame (given that enough heat energy reaches a point in the area where such material exists).

a) See comment 1.1.2.2.2.2.2.2.a.

b) See comment 1.1.2.2.3.2.1.2.b.

> 1.1.2.2.3.2.1.1
A spark or open flame comes in contact with an imported flammable material in the face area of a working panel (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.3.2.1.1.1 ->
Coal cutting, rock cutting or drilling operations cause a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.3.2.1.1.2 ->
Shooting operations cause a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.3.2.1.1.3 ->
Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.3.2.1.1.4 ->
Operation of combustion equipment causes a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.3.2.1.1.5 ->
Operation of mechanical equipment causes a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

- 1.1.2.2.3.2.1.1.6 ->
Use of contraband or other fire hazard causes a spark or open flame

which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

> 1.1.2.2.3.2.2.1
Enough heat energy (without sparks or flame) reaches a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.1.2.2.3.2.2.1.1 ->
Coal cutting, rock cutting, or drilling operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.3.2.2.1.2 ->
Shooting operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.3.2.2.1.3 ->
Operation of electrical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.3.2.2.1.4 ->
Operation of combustion equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.3.2.2.1.5 ->
Operation of mechanical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

- 1.1.2.2.3.2.2.1.6 ->
Use of contraband or other fire hazard causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

> 1.1.2.2.3.2.1.1.1
Coal cutting, rock cutting or drilling operations cause a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.3.2.1.1.1.1 *
Coal cutting, rock cutting or drilling operations are being performed in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.1.1.

- 1.1.2.2.3.2.1.1.1.2 *
Coal cutting, rock cutting or drilling operations cause a spark or open flame in the vicinity of the face area of a working panel (given that such operations are being performed in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.1.2.

- 1.1.2.2.3.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operations in the vicinity of the face area of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.3.2.1.1.2
Shooting operations cause a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.3.2.1.1.2.1 *
Shooting operations are being performed in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.2.2.1.1.2.1.

- 1.1.2.2.3.2.1.1.2.2 *
Shooting operations cause a spark or open flame in the vicinity of the face area of a working panel (given that such operations are being performed in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.2.2.

- 1.1.2.2.3.2.1.1.2.3 *
Spark or open flame caused by shooting operations in the vicinity of the face area of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.3.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.3.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.3.1.

- 1.1.2.2.3.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.3.2.

- 1.1.2.2.3.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the face area of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.3.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with an imported flammable material in the face area

of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.3.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.4.1.

- 1.1.2.2.3.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.4.2.

- 1.1.2.2.3.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of the face area of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.3.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.3.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.5.1.

- 1.1.2.2.3.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of the face area of a working panel (given that such equipment is operating in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.5.2.

- 1.1.2.2.3.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of the face area of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.1.2.2.3.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the face area of a working panel (given that such material is present in the area).

AND

- 1.1.2.2.3.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.6.1.

- 1.1.2.2.3.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the face area of a working panel (given that such use

or hazard occurs in the vicinity).

a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.6.2.

- 1.1.2.2.3.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.1.2.2.3.2.2.1.1
Coal cutting, rock cutting or drilling operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.3.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operations are being performed in the vicinity of the face area of a working panel.

a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.1.1.

- 1.1.2.2.3.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operations in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such operations are being performed in the vicinity).

a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.1.2.

- 1.1.2.2.3.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of the face area of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) This branch represents a group of various flammable materials which will likely have quite different ignition temperatures. In an application to an actual mine, this branch might be split according to specific flammable materials or at least into narrower groups. This would however depend on there being enough data for all the branches. In the event that the branch has a range of ignition temperatures to be considered, the lowest one should probably be used.

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.3.2.2.1.1.4 *
Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of the face area of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.3.2.2.1.2
Shooting operations cause enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.3.2.2.1.2.1 *
  Shooting operations are being performed in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.2.2.1.1.2.1.

- 1.1.2.2.3.2.2.1.2.2 *
  Shooting operations in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such operations are being performed in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.2.2.

- 1.1.2.2.3.2.2.1.2.3 *
  Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the face area of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.3.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.3.2.2.1.2.4 *
  Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the face area of a working panel reaches a point in the face area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.3.2.2.1.3
Operation of electrical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.3.2.2.1.3.1 *
  Electrical equipment is operating in the vicinity of the face area of a working panel.

    a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.3.1.

- 1.1.2.2.3.2.2.1.3.2 *
  Operation of electrical equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

    a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.3.2.

- 1.1.2.2.3.2.2.1.3.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the face area of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.3.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.3.2.2.1.3.4 *
  Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of the face area of a working panel reaches a point in the face area where imported flammable material exists to raise the material to its ignition point (given

that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.3.2.2.1.4
Operation of combustion equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.3.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of the face area of a working panel.

a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.4.1.

- 1.1.2.2.3.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.4.2.

- 1.1.2.2.3.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the face area of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.3.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the face area of a working panel reaches a point in the face area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.3.2.2.1.5
Operation of mechanical equipment causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.3.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of the face area of a working panel.

a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.5.1.

- 1.1.2.2.3.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.5.2.

- 1.1.2.2.3.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the face area of a working panel to raise an imported flammable material to its

ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.3.2.2.1.5.4 *
Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of the face area of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.1.2.2.3.2.2.1.6
Use of contraband or other fire hazard causes enough heat energy (without sparks or flame) at a point in the face area of a working panel where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area).

AND

- 1.1.2.2.3.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the face area of a working panel.

a) This event is identical to event 1.1.2.2.1.2.1.2.1.1.6.1.

- 1.1.2.2.3.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of the face area of a working panel causes excess heat energy to be produced (given that such use or hazard occurs in the vicinity).

a) This event is identical to event 1.1.2.2.1.2.1.2.2.1.6.2.

- 1.1.2.2.3.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.1.2.2.3.2.2.1.6.4 *
Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of the face area of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.2
Initiation of fire in the intake tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

OR

- 1.2.1 ->
Initiation of fire by spontaneous combustion of coal in the seam at the intake tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

- 1.2.2 ->
Ignition of combustible material in the intake tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

> 1.2.1
Initiation of fire by spontaneous combustion of coal in the seam at the intake tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

AND

- 1.2.1.1 *
Presence of coal prone to spontaneous combustion in the seam at the intake tunnel of a working panel.

  a) See comment 1.1.1.1.a

  b) Coal seam can be present in mine areas other than the face. Parts of the seam may be left in the floor or the roof, and tunnel walls are often coal. Usually, these surfaces are covered by wooden lagging and possibly corrugated sheet metal, making the possibility of ignition by an external heat source unlikely. There is, however, a possibility of spontaneous combustion.

- 1.2.1.2 *
Sufficiently high temperatures are maintained in the seam at the intake tunnel of a working panel that would produce spontaneous combustion if no heat were dissipated by air flow (given the type of coal in the seam and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.2.a.

- 1.2.1.3 *
There is an air-flow through the seam at the intake tunnel of a working panel permitting enough oxygen in contact with the coal to allow spontaneous combustion (given that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.3.a.

- 1.2.1.4 *
The flow of air through the seam at the intake tunnel of a working panel does not dissipate enough heat to prevent spontaneous combustion (given that the temperature maintained in the seam is high enough in the absence of such dissipation to produce such a spontaneous combustion, that there is enough air-flow in the seam to provide the required oxygen and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.4.a.

> 1.2.2
Ignition of a combustible material in the intake tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.1 *

Level of oxygen in the air in the intake tunnel of a working panel is sufficient to allow combustion (given that there is no ongoing fire anywhere in the mine).

a) See comment 1.1.2.1.a.

- 1.2.2.2 ->
A combustible material in the intake tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 1.2.2.2
A combustible material in the intake tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.1 ->
Explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.2 ->
Loose coal or accumulated coal dust in the intake tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.3 ->
An imported flammable material in the intake tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 1.2.2.2.1
Explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.1.1 *
Presence of an explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel (given that the level of oxygen in the area is sufficiently high for combustion).

a) As explained in comment 1.1.2.2.1.1.a, methane is released into the mine areas from the coal seam, from mined coal, and from the gob with the majority coming from actively mined coal faces as a result of the mining process. Normally the direction of ventilation in the mine carries methane produced at the face out of the panel by the panel return tunnel and then out of the mine through the main return tunnels. As such the levels of methane in the intake tunnels is usually low and the probability of this event small. Countervailing possibilities are: insufficient ventilation pressure to diffuse methane from coal on conveyor and other sources, a situation causing back-ventilation from the face, malfunction or inadequacy of methane drainage system allowing methane in gob build up and leak into area, stress fracturing of pillars in gassy areas of the coal seam allowing methane to leak into area, a methane leak upstream.

b) As explained in comment 1.1.2.2.1.1.b airborne coal-dust is also produced primarily at the face as a result of the mining process and as such the hazard from this source is relatively low in other areas. Problems could occur where coal is transferred from one conveyance to another or in the event that some explosion or blast of air raises a dust cloud (although it is assumed in the model here that no other fire-causing event is taking place).

c) See comment 1.1.2.2.1.1.c

- 1.2.2.2.1.2 ->
  Explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.2.2.2.1.2
Explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

OR (exclusive)

- 1.2.2.2.1.2.1 ->
  Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.1.2.2 ->
  Mine is evacuated and explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.2.2.2.1.2.1
Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.1.2.1.1 *
  Mine is not evacuated (given that an explosive mixture of methane and/or airborne coal dust is present in the intake tunnel of a working panel).

  a) This event is the logical negative of 1.2.2.2.1.2.2.1

- 1.2.2.2.1.2.1.2 ->
  Explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area, that the mine is not evacuated and that there is no ongoing fire anywhere in the mine).

> 1.2.2.2.1.2.2
Mine is evacuated and explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.1.2.2.1 *
  Mine is evacuated (given that an explosive mixture of methane and/or coal-dust is present in the intake tunnel of a working panel).

  a) See comment 1.1.2.2.1.2.2.1.a. Although regular testing is done mostly at the face, it is possible that spot checks would detect high methane levels in other areas.

Also if methane levels are high in this area it is very likely that they are also high at the face. Thus, there is a correlation between this event and 1.1.2.2.1.2.2.1.

b) This event is the logical negative of 1.2.2.2.1.2.1.1.

- 1.2.2.2.1.2.2.2 *
Explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area, that mine is evacuated and that there is no ongoing fire anywhere in the mine).

a) See comment 1.1.2.2.1.2.2.2.a.

> 1.2.2.2.1.2.1.2
Explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.1.2.1.2.1 ->
A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.1.2.1.2.2 ->
Heat (without sparks or flame) raises an explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

> 1.2.2.2.1.2.1.2.1
A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.1.2.1.2.1.1 ->
A spark or open flame reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.1.2.1.2.1.2 *
An explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point by a spark or open flame (given that a point in the area where such a mixture exists has been reached by a spark or open flame).

a) See comment 1.1.2.2.1.2.1.2.1.2.a.

> 1.2.2.2.1.2.1.2.2
Heat (without sparks or flame) raises an explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.1.2.1.2.2.1 ->

Enough heat energy (without sparks or flame) reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.1.2.1.2.2.2 *
An explosive mixture of methane and/or airborne coal dust in the intake tunnel of a working panel is raised to its ignition point by heat without sparks or flame (given that enough heat energy reaches a point in the area where such a mixture exists).

  a) See comment 1.1.2.2.1.2.1.2.2.2.a.

> 1.2.2.2.1.2.1.2.1.1
A spark or open flame reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.1.2.1.2.1.1.1 ->
Coal cutting, rock cutting or drilling operations cause a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.1.1.2 ->
Shooting operations cause a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.1.1.3 ->
Operation of electrical equipment causes a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.1.1.4 ->
Operation of combustion equipment produces a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.1.1.5 ->
Operation of mechanical equipment produces a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.1.1.6 ->
Use of contraband or other fire hazard causes a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

> 1.2.2.2.1.2.1.2.2.1
Enough heat energy (without sparks or flame) reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.1.2.1.2.2.1.1 ->
  Coal cutting, rock cutting, or drilling operations cause enough heat energy (without sparks or flame) at a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.2.1.2 ->
  Shooting operations cause enough heat energy (without sparks or flame) at a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.2.1.3 ->
  Operation of electrical equipment causes enough heat energy (without sparks or flame) at a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.2.1.4 ->
  Operation of combustion equipment causes enough heat energy (without sparks or flame) at a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.2.1.5 ->
  Operation of mechanical equipment causes enough heat energy (without sparks or flame) at a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.2.2.2.1.2.1.2.2.1.6 ->
  Use of contraband or other fire hazard causes enough heat energy (without sparks or flame) at a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that the mine has not been evacuated).

> 1.2.2.2.1.2.1.2.1.1.1
Coal cutting, rock cutting or drilling operations cause a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.1.1.1.1 *
  Coal cutting, rock cutting or drilling operations are being performed in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

    a) See comments 1.1.2.2.1.2.1.2.1.1.1.1.a, b & c. These operations are rarely done in areas other than the face and developing areas but are occasionally necessary to remove caved material, when new tunnels are developed off old ones, when tunnels are widened or when room is made for the installation of new equipment or structures.

    b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.2.2.2.1.2.1.2.1.1.1.2 *
  Coal cutting, rock cutting or drilling operations cause a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such operations are being performed in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a.

b) This event will differ from the one referenced in comment ´a´ only to the extent that conditions in the area, differences in the way the operation is performed or differences in the equipment used change the probability of a sparks or flame.

- 1.2.2.2.1.2.1.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operations in the vicinity of the intake tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) As explained in comment 1.1.2.2.1.2.1.2.1.1.1.3.b, methane and airborne coal dust concentrations may vary from spot to spot in an area. In the intake tunnel, there will be a general tendency for methane and dust to be heavier near the face. Gas will, however, still tend to collect in roof cavities.

> 1.2.2.2.1.2.1.2.1.1.2
Shooting operations cause a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.1.1.2.1 *
Shooting operations are being performed in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

a) See comment 1.1.2.2.1.2.1.2.1.1.2.1.a. These operations are rarely done in areas other than the face and developing areas but are occasionally necessary to remove caved material, when new tunnels are developed off old ones, when tunnels are widened or when room is made for the installation of new equipment or structures.

b) See comment 1.1.2.2.1.2.1.2.1.1.2.1.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.2.2.2.1.2.1.2.1.1.2.2 *
Shooting operations cause a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such operations are being performed in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.1.1.2.3 *
Spark or open flame caused by shooting operations in the vicinity of the intake tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.2.3.b.

> 1.2.2.2.1.2.1.2.1.1.3
Operation of electrical equipment causes a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

    a) Electric equipment that could be used in an intake tunnel includes electric locomotive engines, conveyor drive motors, lighting, communications, etc. As well a master switching panel for the face electrics is typically installed in the intake.

    b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.2.2.2.1.2.1.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.3.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

> 1.2.2.2.1.2.1.2.1.1.4
Operation of combustion equipment produces a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

    a) Combustion equipment, such as diesel locomotives, are used the intake tunnels.

    b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.2.2.2.1.2.1.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.4.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that

a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

> 1.2.2.2.1.2.1.2.1.1.5
Operation of mechanical equipment produces a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

a) See comment 1.1.2.2.1.2.1.2.1.1.5.1.a. In this area, there could be mine cars and locomotives (electrically or diesel driven), conveyors, coal loaders, and other pieces of large and small mechanical equipment.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.2.2.2.1.2.1.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.5.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

> 1.2.2.2.1.2.1.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which reaches a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

a) See comment 1.1.2.2.1.2.1.2.1.1.6.1.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.2.2.2.1.2.1.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such use or hazard occurs in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.6.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

    c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.2.2.2.1.2.1.2.2.1.1
Coal cutting, rock cutting or drilling operations cause heat energy (without sparks or flame) to reach a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operations are being performed in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

    a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.1.1.

- 1.2.2.2.1.2.1.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operations in the vicinity of the intake tunnel of a working panel cause heat energy to be produced (given that such operations are being performed in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of the intake tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.2.2.2.1.2.1.2.2.1.1.4 *
Enough heat energy (without spark or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of the intake tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

> 1.2.2.2.1.2.1.2.2.1.2
Shooting operations causes heat energy (without spark or flame) to reach a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.2.1.2.1 *
  Shooting operations are being performed in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

    a) This event is identical to 1.2.2.2.1.2.1.2.1.1.2.1

- 1.2.2.2.1.2.1.2.2.1.2.2 *
  Shooting operations in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such an operations is being performed in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.2.1.2.3 *
  Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the intake tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.2.2.2.1.2.1.2.2.1.2.4 *
  Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the intake tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

    c) See comment 1.1.2.2.1.2.1.2.1.1.2.3.b.

> 1.2.2.2.1.2.1.2.2.1.3
> Operation of electrical equipment causes heat energy (without spark or flame) to reach a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.2.1.3.1 *
  Electrical equipment is operating in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

    a) This event is identical to 1.2.2.2.1.2.1.2.1.1.3.1

- 1.2.2.2.1.2.1.2.2.1.3.2 *
  Operation of electrical equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.3.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.2.1.3.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.2.2.2.1.2.1.2.2.1.3.4 *
  Enough heat energy (without spark or flame) caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

> 1.2.2.2.1.2.1.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) to reach a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.2.1.4.1 *
  Combustion equipment is operating in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

    a) This event is identical to 1.2.2.2.1.2.1.2.1.1.4.1

- 1.2.2.2.1.2.1.2.2.1.4.2 *
  Operation of combustion equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.4.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.2.1.4.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.2.2.2.1.2.1.2.2.1.4.4 *
  Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

> 1.2.2.2.1.2.1.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) to reach a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.2.1.5.1 *
  Mechanical equipment is operating in the vicinity of the intake tunnel

of a working panel (given that the mine has not been evacuated).

    a) This event is identical to 1.2.2.2.1.2.1.2.1.1.5.1

- 1.2.2.2.1.2.1.2.2.1.5.2 *
  Operation of mechanical equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.5.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.2.1.5.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.2.2.2.1.2.1.2.2.1.5.4 *
  Enough heat energy (without spark or flame) caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

> 1.2.2.2.1.2.1.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) to reach a point in the intake tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.2.2.2.1.2.1.2.2.1.6.1 *
  Use of contraband or other fire hazard occurs in the vicinity of the intake tunnel of a working panel (given that the mine has not been evacuated).

    a) This event is identical to 1.2.2.2.1.2.1.2.1.1.6.1

- 1.2.2.2.1.2.1.2.2.1.6.2 *
  Use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

    a) This might occur under much the same circumstances as 1.2.2.2.1.2.1.2.1.1.6.2.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.2.2.2.1.2.1.2.2.1.6.3 *
  Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.2.2.2.1.2.1.2.2.1.6.4 *
  Enough heat energy (without spark or flame) caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel reaches a point in that area where an explosive

mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.3.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.2.2.2.2
Loose coal or accumulated coal dust in the intake tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.2.1 *
  Presence of loose coal or accumulated coal dust in the intake tunnel of a working panel.

  a) See comment 1.1.2.2.2.1.a.

- 1.2.2.2.2.2 ->
  Loose coal or accumulated coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.2.2.2.2.2
Loose coal or accumulated coal dust in the intake tunnel of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.2.2.1 ->
  A spark or open flame raises loose coal or accumulated coal dust in the intake tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.2.2.2 ->
  Heat (without flame or spark) raises loose coal or accumulated coal dust in the intake tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.2.2.3 *
  Spontaneous combustion of loose coal or accumulated coal dust in the intake tunnel of a working panel (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.2.2.2.3.a.

> 1.2.2.2.2.2.1
A spark or open flame raises loose coal or accumulated coal dust in the intake tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.2.2.1.1 ->
  A spark or open flame comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such

material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.2.2.1.2 *
  Loose coal or accumulated coal dust in the intake tunnel of a working panel is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

  a) See comment 1.1.2.2.2.2.1.2.a.

  b) See comment 1.1.2.2.2.2.1.2.b.

> 1.2.2.2.2.2.2
Heat (without flame or spark) raises loose coal or accumulated coal dust in the intake tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.2.2.2.1 ->
  Heat energy (without spark or flame) reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.2.2.2.2 *
  Loose coal or accumulated coal dust in the intake tunnel of a working panel is raised to its ignition point by heat energy (without spark or flame) (given that heat energy reaches a point in the area where such material exists).

  a) See comment 1.1.2.2.2.2.2.2.a.

  b) See comment 1.1.2.2.2.2.1.2.b.

> 1.2.2.2.2.2.1.1
A spark or open flame comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.2.2.1.1.1 ->
  Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.2.2.1.1.2 ->
  Shooting operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.2.2.1.1.3 ->
  Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.2.2.1.1.4 ->
  Operation of combustion equipment produces a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.2.2.1.1.5 ->
  Operation of mechanical equipment produces a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.2.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

> 1.2.2.2.2.2.2.1
Heat energy (without spark or flame) reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.2.2.2.1.1 ->
  Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.2.2.2.2.2.2.1.2 ->
  Shooting operation causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.2.2.2.2.2.2.1.3 ->
  Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.2.2.2.2.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.2.2.2.2.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.2.2.2.2.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

> 1.2.2.2.2.2.1.1.1
Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.2.2.1.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.1.1.

- 1.2.2.2.2.2.1.1.1.2 *
  Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.1.2.

- 1.2.2.2.2.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of the intake tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.2.2.1.1.2
Shooting operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.2.2.1.1.2.1 *
Shooting operation is being performed in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.2.1.

- 1.2.2.2.2.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.2.2.

- 1.2.2.2.2.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of the intake tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.2.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.2.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.3.1.

- 1.2.2.2.2.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.3.2.

- 1.2.2.2.2.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.2.2.1.1.4
Operation of combustion equipment causes a spark or open flame which

comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.2.2.1.1.4.1 *
  Combustion equipment is operating in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.4.1.

- 1.2.2.2.2.2.1.1.4.2 *
  Operation of combustion equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.4.2.

- 1.2.2.2.2.2.1.1.4.3 *
  Spark or open flame caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.2.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.2.2.1.1.5.1 *
  Mechanical equipment is operating in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.5.1.

- 1.2.2.2.2.2.1.1.5.2 *
  Operation of mechanical equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.5.2.

- 1.2.2.2.2.2.1.1.5.3 *
  Spark or open flame caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.2.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.2.2.1.1.6.1 *
  Use of contraband or other fire hazard occurs in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.6.1.

- 1.2.2.2.2.2.1.1.6.2 *
  Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such use or hazard occurs in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.6.2.

- 1.2.2.2.2.2.1.1.6.3 *
  Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.2.2.2.2.2.2.1.1
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.2.2.2.2.2.2.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.1.1.

- 1.2.2.2.2.2.2.1.1.2 *
  Coal cutting, rock cutting or drilling operation in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.1.2.

- 1.2.2.2.2.2.2.1.1.3 *
  Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting, or drilling operations in the vicinity of the intake tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a.

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.2.2.2.1.1.4 *
  Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting, or drilling operations in the vicinity of the intake tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.2.2.2.1.2
Shooting operation causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.2.2.2.2.2.2.1.2.1 *
  Shooting operation is being performed in the vicinity of the intake tunnel of a working panel.

a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.2.1.

- 1.2.2.2.2.2.2.1.2.2 *
  Shooting operation in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.2.2.

- 1.2.2.2.2.2.2.1.2.3 *
  Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the intake tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.2.2.2.1.2.4 *
  Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the intake tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.2.2.2.1.3
> Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.2.2.2.2.2.2.1.3.1 *
  Electrical equipment is operating in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.3.1.

- 1.2.2.2.2.2.2.1.3.2 *
  Operation of electrical equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.3.2.

- 1.2.2.2.2.2.2.1.3.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.2.2.2.1.3.4 *
  Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.2.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.2.2.2.2.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.4.1.

- 1.2.2.2.2.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.4.2.

- 1.2.2.2.2.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.2.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.2.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.2.2.2.2.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.5.1.

- 1.2.2.2.2.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.5.2.

- 1.2.2.2.2.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.2.2.2.1.5.4 *
Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.2.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.2.2.2.2.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the intake tunnel of a working panel.

    a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.6.1.

- 1.2.2.2.2.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

    a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.6.2.

- 1.2.2.2.2.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.2.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.2.2.2.1.6.4 *
Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

    b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.2.2.2.3
An imported flammable material in the intake tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.3.1 *
Presence of an imported flammable material in structures, in equipment, or lying loose at the intake tunnel of a working panel.

    a) See comments 1.1.2.2.3.1.a, b & c.

- 1.2.2.2.3.2 ->
An imported flammable material in the intake tunnel of a working panel is raised to its ignition point (given that such material is present

in the area and that there is no ongoing fire anywhere in the mine).

> 1.2.2.2.3.2
An imported flammable material in the intake tunnel of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.3.2.1 ->
A spark or open flame raises an imported flammable material in the intake tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.3.2.2 ->
Heat (without flame or spark) raises an imported flammable material in the intake tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.3.2.3 *
Spontaneous combustion of an imported flammable material in the intake tunnel of a working panel (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.2.2.2.2.3.a.

> 1.2.2.2.3.2.1
A spark or open flame raises an imported flammable material in the intake tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.3.2.1.1 ->
A spark or open flame comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.3.2.1.2 *
An imported flammable material in the intake tunnel of a working panel is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

    a) See comment 1.1.2.2.2.2.1.2.a.

    b) See comment 1.1.2.2.3.2.1.2.b.

> 1.2.2.2.3.2.2
Heat (without flame or spark) raises an imported flammable material in the intake tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.2.2.2.3.2.2.1 ->
Heat energy (without spark or flame) reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.2.2.2.3.2.2.2 *
An imported flammable material in the intake tunnel of a working panel is raised to its ignition point by heat without spark or flame (given that heat energy reaches a point in the area where such material

exists).

a) See comment 1.1.2.2.2.2.2.2.a.

b) See comment 1.1.2.2.3.2.1.2.b.

> 1.2.2.2.3.2.1.1
A spark or open flame comes in contact with an imported flammable material in the intake tunnel of a working panel (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.3.2.1.1.1 ->
Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.3.2.1.1.2 ->
Shooting operation causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.3.2.1.1.3 ->
Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.3.2.1.1.4 ->
Operation of combustion equipment produces a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.3.2.1.1.5 ->
Operation of mechanical equipment produces a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

- 1.2.2.2.3.2.1.1.6 ->
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

> 1.2.2.2.3.2.2.1
Heat energy (without spark or flame) reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.2.2.2.3.2.2.1.1 ->
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.2.2.2.3.2.2.1.2 ->
Shooting operation causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.2.2.2.3.2.2.1.3 ->
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel

where an imported flammable material exists (given that such material is present in the area).

- 1.2.2.2.3.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.2.2.2.3.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.2.2.2.3.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

> 1.2.2.2.3.2.1.1.1
  Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.3.2.1.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.1.1.

- 1.2.2.2.3.2.1.1.1.2 *
  Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.1.2.

- 1.2.2.2.3.2.1.1.1.3 *
  Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of the intake tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.3.2.1.1.2
  Shooting operation causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.3.2.1.1.2.1 *
  Shooting operation is being performed in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.2.1.

- 1.2.2.2.3.2.1.1.2.2 *
  Shooting operation causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.2.2.

- 1.2.2.2.3.2.1.1.2.3 *

Spark or open flame caused by shooting operation in the vicinity of the intake tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.3.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.3.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the intake tunnel of a working panel.

a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.3.1.

- 1.2.2.2.3.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.3.2.

- 1.2.2.2.3.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.3.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.3.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of the intake tunnel of a working panel.

a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.4.1.

- 1.2.2.2.3.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.4.2.

- 1.2.2.2.3.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.3.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which

comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.3.2.1.1.5.1 *
  Mechanical equipment is operating in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.5.1.

- 1.2.2.2.3.2.1.1.5.2 *
  Operation of mechanical equipment causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.5.2.

- 1.2.2.2.3.2.1.1.5.3 *
  Spark or open flame caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.2.2.2.3.2.1.1.6
> Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the intake tunnel of a working panel (given that such material is present in the area).

AND

- 1.2.2.2.3.2.1.1.6.1 *
  Use of contraband or other fire hazard occurs in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.6.1.

- 1.2.2.2.3.2.1.1.6.2 *
  Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the intake tunnel of a working panel (given that such use or hazard occurs in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.6.2.

- 1.2.2.2.3.2.1.1.6.3 *
  Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.2.2.2.3.2.2.1.1
> Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.2.2.2.3.2.2.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the intake tunnel of a working panel.

a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.1.1.

- 1.2.2.2.3.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.1.2.

- 1.2.2.2.3.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of the intake tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.3.2.2.1.1.4 *
Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of the intake tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.3.2.2.1.2
Shooting operation causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.2.2.2.3.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of the intake tunnel of a working panel.

a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.2.1.

- 1.2.2.2.3.2.2.1.2.2 *
Shooting operation in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.2.2.

- 1.2.2.2.3.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the intake tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.3.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the intake tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.3.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.2.2.2.3.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of the intake tunnel of a working panel.

    a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.3.1.

- 1.2.2.2.3.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.3.2.

- 1.2.2.2.3.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.3.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.3.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.3.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.2.2.2.3.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of the intake tunnel of a working panel.

    a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.4.1.

- 1.2.2.2.3.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.4.2.

- 1.2.2.2.3.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.3.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.3.2.2.1.4.4 *
  Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.3.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.2.2.2.3.2.2.1.5.1 *
  Mechanical equipment is operating in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.5.1.

- 1.2.2.2.3.2.2.1.5.2 *
  Operation of mechanical equipment in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.2.2.2.1.2.1.2.2.1.5.2.

- 1.2.2.2.3.2.2.1.5.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.3.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.3.2.2.1.5.4 *
  Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of the intake tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.2.2.2.3.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in the intake tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.2.2.2.3.2.2.1.6.1 *
  Use of contraband or other fire hazard occurs in the vicinity of the intake tunnel of a working panel.

  a) This event is identical to event 1.2.2.2.1.2.1.2.1.1.6.1.

- 1.2.2.2.3.2.2.1.6.2 *
  Use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

- 1.2.2.2.3.2.2.1.6.3 *
  Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.3.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.2.2.2.3.2.2.1.6.4 *
  Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of the intake tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.3
Initiation of fire in the return tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

OR

- 1.3.1 ->
Initiation of fire by spontaneous combustion of coal in the seam at the return tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

- 1.3.2 ->
Ignition of combustible material in the return tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

> 1.3.1
Initiation of fire by spontaneous combustion of coal in the seam at the return tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

AND

- 1.3.1.1 *
Presence of coal prone to spontaneous combustion in the seam at the return tunnel of a working panel.

  a) See comment 1.1.1.1.a

  b) See comment 1.2.1.1.b.

- 1.3.1.2 *
Sufficiently high temperatures are maintained for long enough in the seam at the return tunnel of a working panel that would produce spontaneous combustion if no heat were dissipated by air flow (given the type of coal in the seam and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.2.a.

- 1.3.1.3 *
There is an air-flow through the seam at the return tunnel of a working panel permitting enough oxygen in contact with the coal to allow spontaneous combustion (given that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.3.a.

- 1.3.1.4 *
The flow of air through the seam at the return tunnel of a working panel does not dissipate enough heat to prevent spontaneous combustion (given that the temperature maintained in the seam is high enough in the absence of such dissipation to produce such a spontaneous combustion, that there is enough air-flow in the seam to provide the required oxygen and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.4.a.

> 1.3.2
Ignition of a combustible material in the return tunnel of a working panel (given that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.1 *
Level of oxygen in the air in the return tunnel of a working panel is sufficient to allow combustion (given that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.2.1.a.

- 1.3.2.2 ->
A combustible material in the return tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 1.3.2.2
A combustible material in the return tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.1 ->
Explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.2 ->
Loose coal or accumulated coal dust in the return tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.3 ->
An imported flammable material in the return tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 1.3.2.2.1
Explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.1.1 *
Presence of an explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel (given that the level of oxygen in the area is sufficiently high for combustion).

    a) As explained in comment 1.1.2.2.1.1.a, methane is released into the mine areas from the coal seam, from mined coal, and from the gob with the majority coming from actively mined coal faces as a result of the mining process. Normally the direction of ventilation in the mine carries methane produced at the face out of the panel by the panel return tunnel and then out of the mine through the main return tunnels. Thus the level of methane in this area tends to be relatively high. Generally, there is an attempt to control mine ventilation so that the methane is diluted to safe levels. Methane can also come from the gob if air flow is allowed to leak through. A defective a valve or leaking pipe in the gob methane drainage system is another possibility.

    b) The level of airborne coal dust may also be high the face but should drop off as it settles out.

    c) See comment 1.1.2.2.1.1.c

- 1.3.2.2.1.2 ->
Explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.3.2.2.1.2
Explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

OR (exclusive)

- 1.3.2.2.1.2.1 ->
Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.1.2.2 ->
Mine is evacuated and explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.3.2.2.1.2.1
Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.1.2.1.1 *
Mine is not evacuated (given that an explosive mixture of methane and/or airborne coal dust is present in the return tunnel of a working panel).

    a) This event is the logical negative of 1.3.2.2.1.2.2.1.

- 1.3.2.2.1.2.1.2 ->
Explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area, that the mine is not evacuated and that there is no ongoing fire anywhere in the mine).

> 1.3.2.2.1.2.2
Mine is evacuated and explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.1.2.2.1 *
Mine is evacuated (given that an explosive mixture of methane and/or coal-dust is present in the return tunnel of a working panel).

    a) See comment 1.2.2.2.1.2.2.1.a.

    b) This event is the logical negative of 1.3.2.2.1.2.1.1.

- 1.3.2.2.1.2.2.2 *
Explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area, that mine is evacuated and that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.2.2.1.2.2.2.a.

> 1.3.2.2.1.2.1.2
Explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point (given that such a mixture is present in the area, that the mine has not been

evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.1.2.1.2.1 ->
  A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).
- 1.3.2.2.1.2.1.2.2 ->
  Heat (without flame or spark) raises an explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

> 1.3.2.2.1.2.1.2.1
A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.1.2.1.2.1.1 ->
  A spark or open flame reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).
- 1.3.2.2.1.2.1.2.1.2 *
  An explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point by a spark or open flame (given that a point in the area where such a mixture exists has been reached by a spark or open flame).

  a) See comment 1.1.2.2.1.2.1.2.1.2.a.

> 1.3.2.2.1.2.1.2.2
Heat (without flame or spark) raises an explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.1.2.1.2.2.1 ->
  Heat energy (without spark or flame) reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).
- 1.3.2.2.1.2.1.2.2.2 *
  An explosive mixture of methane and/or airborne coal dust in the return tunnel of a working panel is raised to its ignition point by heat without a spark or flame (given that heat energy reaches a point in the area where such a mixture exists).

  a) See comment 1.1.2.2.1.2.1.2.2.2.a.

> 1.3.2.2.1.2.1.2.1.1
A spark or open flame reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area,

that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.1.2.1.2.1.1.1 ->
Coal cutting, rock cutting or drilling operation causes a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.1.1.2 ->
Shooting operation causes a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.1.1.3 ->
Operation of electrical equipment causes a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.1.1.4 ->
Operation of combustion equipment produces a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.1.1.5 ->
Operation of mechanical equipment produces a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.1.1.6 ->
Use of contraband or other fire hazard causes a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

> 1.3.2.2.1.2.1.2.2.1
Heat energy (without spark or flame) reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.1.2.1.2.2.1.1 ->
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.2.1.2 ->
Shooting operation causes causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.2.1.3 ->
Operation of electrical equipment causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine

has not been evacuated).

- 1.3.2.2.1.2.1.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 1.3.2.2.1.2.1.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

> 1.3.2.2.1.2.1.2.1.1.1
Coal cutting, rock cutting or drilling operation causes a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.1.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

  a) See comment 1.2.2.2.1.2.1.2.1.1.1.1.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.3.2.2.1.2.1.2.1.1.1.2 *
  Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such an operation is being performed in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a.

  b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.1.1.1.3 *
  Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of the return tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) As explained in comment 1.1.2.2.1.2.1.2.1.1.1.3.b, methane and airborne coal dust concentrations may vary from spot to spot in an area. In the return tunnel, this variability should be less evident with higher methane and airborne coal dust levels nearer the face. Methane will still tend to collect in roof cavities.

> 1.3.2.2.1.2.1.2.1.1.2
Shooting operation causes a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.1.1.2.1 *
Shooting operation is being performed in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

  a) See comment 1.2.2.2.1.2.1.2.1.1.2.1.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.3.2.2.1.2.1.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such an operation is being performed in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of the return tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

> 1.3.2.2.1.2.1.2.1.1.3
Operation of electrical equipment causes a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

  a) Electric equipment tends not to be used in return tunnels because of the high methane levels.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.3.2.2.1.2.1.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.3.2.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

> 1.3.2.2.1.2.1.2.1.1.4
Operation of combustion equipment produces a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

  a) Combustion equipment tends not to be used in return tunnels because of the high methane levels.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.3.2.2.1.2.1.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.4.2.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

> 1.3.2.2.1.2.1.2.1.1.5
Operation of mechanical equipment produces a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

  a) See comment 1.1.2.2.1.2.1.2.1.1.5.1.a. In this area, all types of equipment are kept to a minimum because of the potentially high methane levels. The major mechanical items would be mine cars (which are usually rope hauled) and smaller pieces.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.3.2.2.1.2.1.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.5.2.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal

dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

> 1.3.2.2.1.2.1.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which reaches a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

a) See comment 1.1.2.2.1.2.1.2.1.1.6.1.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 1.3.2.2.1.2.1.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such use or hazard occurs in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.6.2.a.

b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.3.2.2.1.2.1.2.2.1.1
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.1.1.

- 1.3.2.2.1.2.1.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a.

b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of the return tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.3.2.2.1.2.1.2.2.1.1.4 *
Enough heat energy (without spark or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of the return tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

> 1.3.2.2.1.2.1.2.2.1.2
Shooting operation causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

a) This event is identical to 1.3.2.2.1.2.1.2.1.1.2.1

- 1.3.2.2.1.2.1.2.2.1.2.2 *
Shooting operation in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the return tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.3.2.2.1.2.1.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the return tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.2.3.b.

> 1.3.2.2.1.2.1.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.2.1.3.1 *
  Electrical equipment is operating in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

  a) This event is identical to 1.3.2.2.1.2.1.2.1.1.3.1

- 1.3.2.2.1.2.1.2.2.1.3.2 *
  Operation of electrical equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.3.2.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.2.1.3.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.3.2.2.1.2.1.2.2.1.3.4 *
  Enough heat energy (without spark or flame) caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

> 1.3.2.2.1.2.1.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.2.1.4.1 *
  Combustion equipment is operating in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

  a) This event is identical to 1.3.2.2.1.2.1.2.1.1.4.1

- 1.3.2.2.1.2.1.2.2.1.4.2 *
  Operation of combustion equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.4.2.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.3.2.2.1.2.1.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

> 1.3.2.2.1.2.1.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

  a) This event is identical to 1.3.2.2.1.2.1.2.1.1.5.1

- 1.3.2.2.1.2.1.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.5.2.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.3.2.2.1.2.1.2.2.1.5.4 *
Enough heat energy (without spark or flame) caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

  b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

> 1.3.2.2.1.2.1.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) to reach a point in the return tunnel of a working panel where an explosive mixture of methane and/or airborne coal dust

exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 1.3.2.2.1.2.1.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the return tunnel of a working panel (given that the mine has not been evacuated).

    a) This event is identical to 1.3.2.2.1.2.1.2.1.1.6.1

- 1.3.2.2.1.2.1.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

    a) This might occur under much the same circumstances as 1.3.2.2.1.2.1.2.1.1.6.2.

    b) See comment 1.3.2.2.1.2.1.2.1.1.1.2.b.

- 1.3.2.2.1.2.1.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 1.3.2.2.1.2.1.2.2.1.6.4 *
Enough heat energy (without spark or flame) caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 1.3.2.2.1.2.1.2.1.1.1.3.b.

    c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.3.2.2.2
Loose coal or accumulated coal dust in the return tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.2.1 *
Presence of loose coal or accumulated coal dust in the return tunnel of a working panel.

    a) See comment 1.1.2.2.2.1.a.

- 1.3.2.2.2.2 ->
Loose coal or accumulated coal dust in the return tunnel of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.3.2.2.2.2
Loose coal or accumulated coal dust in the return tunnel of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.2.2.1 ->
A spark or open flame raises loose coal or accumulated coal dust in the return tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.2.2.2 ->
Heat (without flame or spark) raises loose coal or accumulated coal dust in the return tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.2.2.3 *
Spontaneous combustion of loose coal or accumulated coal dust in the return tunnel of a working panel (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.2.2.2.3.a.

> 1.3.2.2.2.2.1
A spark or open flame raises loose coal or accumulated coal dust in the return tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.2.2.1.1 ->
A spark or open flame comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.2.2.1.2 *
Loose coal or accumulated coal dust in the return tunnel of a working panel is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

  a) See comment 1.1.2.2.2.2.1.2.a.

  b) See comment 1.1.2.2.2.2.1.2.b.

> 1.3.2.2.2.2.2
Heat (without flame or spark) raises loose coal or accumulated coal dust in the return tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.2.2.2.1 ->
Heat energy (without spark or flame) reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.2.2.2.2 *
Loose coal or accumulated coal dust in the return tunnel of a working panel is raised to its ignition point by heat energy (without spark or flame) (given that heat energy reaches a point in the area where such material exists).

  a) See comment 1.1.2.2.2.2.2.2.a.

  b) See comment 1.1.2.2.2.2.1.2.b.

> 1.3.2.2.2.2.1.1

A spark or open flame comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.2.2.1.1.1 ->
  Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.2.2.1.1.2 ->
  Shooting operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.2.2.1.1.3 ->
  Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.2.2.1.1.4 ->
  Operation of combustion equipment produces a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.2.2.1.1.5 ->
  Operation of mechanical equipment produces a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.2.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

> 1.3.2.2.2.2.2.1
> Heat energy (without spark or flame) reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.2.2.2.1.1 ->
  Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.3.2.2.2.2.2.1.2 ->
  Shooting operation causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.3.2.2.2.2.2.1.3 ->
  Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.3.2.2.2.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.3.2.2.2.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 1.3.2.2.2.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

> 1.3.2.2.2.2.1.1.1
Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.2.2.1.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.1.1.

- 1.3.2.2.2.2.1.1.1.2 *
  Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.1.2.

- 1.3.2.2.2.2.1.1.1.3 *
  Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of the return tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.3.2.2.2.2.1.1.2
Shooting operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.2.2.1.1.2.1 *
  Shooting operation is being performed in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.2.1.

- 1.3.2.2.2.2.1.1.2.2 *
  Shooting operation causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.2.2.

- 1.3.2.2.2.2.1.1.2.3 *
  Spark or open flame caused by shooting operation in the vicinity of the return tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.3.2.2.2.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.2.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.3.1.

- 1.3.2.2.2.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.3.2.

- 1.3.2.2.2.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.3.2.2.2.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.2.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.4.1.

- 1.3.2.2.2.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.4.2.

- 1.3.2.2.2.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.3.2.2.2.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.2.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.5.1.

- 1.3.2.2.2.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.5.2.

- 1.3.2.2.2.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.3.2.2.2.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.2.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.6.1.

- 1.3.2.2.2.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such use or hazard occurs in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.6.2.

- 1.3.2.2.2.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.3.2.2.2.2.2.1.1
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.3.2.2.2.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.1.1.

- 1.3.2.2.2.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.1.2.

- 1.3.2.2.2.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting, or drilling operations in the vicinity of the return tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.2.2.2.1.1.3.a.

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.2.2.2.1.1.4 *
Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting, or drilling operations in the vicinity of the return tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.2.2.2.1.2
Shooting operation causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.3.2.2.2.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of the return tunnel of a working panel.

    a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.2.1.

- 1.3.2.2.2.2.2.1.2.2 *
Shooting operation in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

    a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.2.2.

- 1.3.2.2.2.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the return tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.2.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.2.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the return tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.2.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.3.2.2.2.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.3.1.

- 1.3.2.2.2.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.3.2.

- 1.3.2.2.2.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.2.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.2.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

.AND

- 1.3.2.2.2.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.4.1.

- 1.3.2.2.2.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.4.2.

- 1.3.2.2.2.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.2.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.2.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.3.2.2.2.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.5.1.

- 1.3.2.2.2.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.5.2.

- 1.3.2.2.2.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.2.2.2.1.5.4 *
Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.2.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 1.3.2.2.2.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.6.1.

- 1.3.2.2.2.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.6.2.

- 1.3.2.2.2.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.2.2.2.1.6.4 *
Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.3.2.2.3
An imported flammable material in the return tunnel of a working panel is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.3.1 *
Presence of an imported flammable material in structures, in equipment, or lying loose at the return tunnel of a working panel.

a) See comments 1.1.2.2.3.1.a, b & c.

- 1.3.2.2.3.2 ->
An imported flammable material in the return tunnel of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 1.3.2.2.3.2
An imported flammable material in the return tunnel of a working panel is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.3.2.1 ->
A spark or open flame raises an imported flammable material in the return tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.3.2.2 ->
Heat (without flame or spark) raises an imported flammable material in the return tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.3.2.3 *
Spontaneous combustion of an imported flammable material in the return tunnel of a working panel (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

a) See comment 1.1.2.2.2.2.3.a.

> 1.3.2.2.3.2.1
A spark or open flame raises an imported flammable material in the return tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.3.2.1.1 ->
  A spark or open flame comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.3.2.1.2 *
  An imported flammable material in the return tunnel of a working panel is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

  a) See comment 1.1.2.2.2.2.1.2.a.

  b) See comment 1.1.2.2.3.2.1.2.b.

> 1.3.2.2.3.2.2
Heat (without flame or spark) raises an imported flammable material in the return tunnel of a working panel to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 1.3.2.2.3.2.2.1 ->
  Heat energy (without spark or flame) reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 1.3.2.2.3.2.2.2 *
  An imported flammable material in the return tunnel of a working panel is raised to its ignition point by heat without spark or flame (given that heat energy reaches a point in the area where such material exists).

  a) See comment 1.1.2.2.2.2.2.2.a.

  b) See comment 1.1.2.2.3.2.1.2.b.

> 1.3.2.2.3.2.1.1
A spark or open flame comes in contact with an imported flammable material in the return tunnel of a working panel (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.3.2.1.1.1 ->
  Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.3.2.1.1.2 ->
  Shooting operation causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.3.2.1.1.3 ->
  Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.3.2.1.1.4 ->
  Operation of combustion equipment produces a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.3.2.1.1.5 ->
  Operation of mechanical equipment produces a spark or open flame which

comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

- 1.3.2.2.3.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

> 1.3.2.2.3.2.2.1
> Heat energy (without spark or flame) reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 1.3.2.2.3.2.2.1.1 ->
  Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.3.2.2.3.2.2.1.2 ->
  Shooting operation causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.3.2.2.3.2.2.1.3 ->
  Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.3.2.2.3.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.3.2.2.3.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

- 1.3.2.2.3.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

> 1.3.2.2.3.2.1.1.1
> Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.3.2.1.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.1.1.

- 1.3.2.2.3.2.1.1.1.2 *
  Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such an operation is being performed in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.1.2.

- 1.3.2.2.3.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of the return tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

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> 1.3.2.2.3.2.1.1.2
Shooting operation causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.3.2.1.1.2.1 *
Shooting operation is being performed in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.2.1.

- 1.3.2.2.3.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such an operation is being performed in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.2.2.

- 1.3.2.2.3.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of the return tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

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> 1.3.2.2.3.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.3.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.3.1.

- 1.3.2.2.3.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.3.2.

- 1.3.2.2.3.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

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> 1.3.2.2.3.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.3.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.4.1.

- 1.3.2.2.3.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.4.2.

- 1.3.2.2.3.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.3.2.2.3.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.3.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.5.1.

- 1.3.2.2.3.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such equipment is operating in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.5.2.

- 1.3.2.2.3.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 1.3.2.2.3.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the return tunnel of a working panel (given that such material is present in the area).

AND

- 1.3.2.2.3.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.6.1.

- 1.3.2.2.3.2.1.1.6.2 *
  Use of contraband or other fire hazard causes a spark or open flame in the vicinity of the return tunnel of a working panel (given that such use or hazard occurs in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.6.2.

- 1.3.2.2.3.2.1.1.6.3 *
  Spark or open flame caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.3.2.2.3.2.2.1.1
Coal cutting, or rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.3.2.2.3.2.2.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.1.1.

- 1.3.2.2.3.2.2.1.1.2 *
  Coal cutting, rock cutting or drilling operation in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.1.2.

- 1.3.2.2.3.2.2.1.1.3 *
  Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of the return tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.3.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.3.2.2.1.1.4 *
  Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of the return tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.3.2.2.1.2
Shooting operation causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.3.2.2.3.2.2.1.2.1 *

Shooting operation is being performed in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.2.1.

- 1.3.2.2.3.2.2.1.2.2 *
Shooting operation in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.2.2.

- 1.3.2.2.3.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of the return tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.3.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the return tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.3.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.3.2.2.3.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.3.1.

- 1.3.2.2.3.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.3.2.

- 1.3.2.2.3.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.3.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.3.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.3.2.2.3.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.4.1.

- 1.3.2.2.3.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.4.2.

- 1.3.2.2.3.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.3.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.3.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.3.2.2.3.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of the return tunnel of a working panel.

a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.5.1.

- 1.3.2.2.3.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.5.2.

- 1.3.2.2.3.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.3.2.2.1.5.4 *
  Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of the return tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 1.3.2.2.3.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in the return tunnel of a working panel where an imported flammable material exists (given that such material is present in the area).

AND

- 1.3.2.2.3.2.2.1.6.1 *
  Use of contraband or other fire hazard occurs in the vicinity of the return tunnel of a working panel.

  a) This event is identical to event 1.3.2.2.1.2.1.2.1.1.6.1.

- 1.3.2.2.3.2.2.1.6.2 *
  Use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

  a) This event is identical to event 1.3.2.2.1.2.1.2.2.1.6.2.

- 1.3.2.2.3.2.2.1.6.3 *
  Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.3.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 1.3.2.2.3.2.2.1.6.4 *
  Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of the return tunnel of a working panel reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 1.4
Initiation of fire in the gob area of a working panel (given that there is no ongoing fire anywhere in the mine).

OR

- 1.4.1 ->
Initiation of fire by spontaneous combustion of coal and/or other materials in the gob area of a working panel (given that there is no ongoing fire anywhere in the mine).

- 1.4.2 ->
Ignition of combustible material in the gob area of a working panel (given that there is no ongoing fire anywhere in the mine).

> 1.4.1
Initiation of fire by spontaneous combustion of coal and/or other materials in the gob area of a working panel (given that there is no ongoing fire anywhere in the mine).

AND

- 1.4.1.1 *
Presence of coal or other materials prone to spontaneous combustion in the gob of a working panel.

  a) See comment 1.1.1.1.a

  b) The gob is an abandoned area that consists of caved rock and unmined coal, as well as imported materials left behind as refuse as the face advances or retreates.

- 1.4.1.2 *
Sufficiently high temperatures are maintained for long enough in the gob area of a working panel that would produce spontaneous combustion if no heat were dissipated by air flow (given the type of coal and other materials in the gob, and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.2.a.

- 1.4.1.3 *
There is an air-flow through the gob of a working panel permitting enough oxygen in contact with the coal and other materials to allow spontaneous combustion (given that there is no ongoing fire anywhere in the mine).

  a) In the advance mining method, there is considerable danger of air flow intended to ventilate the face area will "short circuit" through the gob, both reducing air flow at the face and increasing the danger of a "gob" fire through spontaneous combustion. Because of this problem some attempt is usually made at sealing the area to make it air tight. However there is usually some level of leakage. In the retreat method there is considerably less problem with this. However, in both methods there are still possibilities for air leakage as described in comment 1.1.1.2.a. The fact the coal and other material is usually in a broken up state also allows for good air circulation.

- 1.4.1.4 *
The flow of air through the gob a working panel does not dissipate enough heat to prevent spontaneous combustion (given that the temperature maintained in the gob is high enough in the absence of such dissipation to produce such a spontaneous combustion, that there is enough air-flow in the gob to provide the required oxygen and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.4.a.

> 1.4.2 *
Ignition of a combustible material in the gob area of a working panel (given that there is no ongoing fire anywhere in the mine).

a) Because the area is inaccessible, there is little possibility of an ignition by other than spontaneous combustion. This event is to defined as that possibility but will not be developed further in this model.

> 2
Initiation of fire in a main tunnel or at a permanent installation (given that there is no ongoing fire anywhere in the mine).

OR

- 2.1 ->
Initiation of fire by spontaneous combustion of coal in the seam at a main tunnel or at a permanent installation (given that there is no ongoing fire anywhere in the mine).

- 2.2 ->
Ignition of combustible material in a main tunnel or at a permanent installation (given that there is no ongoing fire anywhere in the mine).

> 2.1
Initiation of fire by spontaneous combustion of coal in the seam at a main tunnel or at a permanent installation (given that there is no ongoing fire anywhere in the mine).

AND

- 2.1.1 *
Presence of coal prone to spontaneous combustion in the seam at a main tunnel or at a permanent installation.

    a) See comment 1.1.1.1.a.

    b) See comment 1.2.1.1.b.

- 2.1.2 *
Sufficiently high temperatures are maintained for long enough in the seam at a main tunnel or at a permanent installation that would produce spontaneous combustion if no heat were dissipated by air flow (given the type of coal in the seam and that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.1.2.a.

- 2.1.3 *
There is an air-flow through the seam at a main tunnel or at a permanent installation permitting enough oxygen in contact with the coal to allow spontaneous combustion (given that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.1.3.a.

- 2.1.4 *
The flow of air through the seam at a main tunnel or at a permanent installation does not dissipate enough heat to prevent spontaneous combustion (given that the temperature maintained in the seam is high enough in the absence of such dissipation to produce such a spontaneous combustion, that there is enough air-flow in the seam to provide the required oxygen and that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.1.4.a.

> 2.2
Ignition of a combustible material in a main tunnel or at a permanent installation (given that there is no ongoing fire anywhere in the mine).

AND

- 2.2.1 *
Level of oxygen in the air in a main tunnel or at a permanent installation is sufficient to allow combustion (given that there is no ongoing fire anywhere in the mine).

a) See comment 1.1.2.1.a.

- 2.2.2 ->
  A combustible material in a main tunnel or at a permanent installation is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 2.2.2
> A combustible material in a main tunnel or at a permanent installation is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.1 ->
  Explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).
- 2.2.2.2 ->
  Loose coal or accumulated coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).
- 2.2.2.3 ->
  An imported flammable material in a main tunnel or at a permanent installation is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 2.2.2.1
> Explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.1.1 *
  Presence of an explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation (given that the level of oxygen in the area is sufficiently high for combustion).

  a) As explained in comments 1.2.2.2.1.1.a and 1.3.2.2.1.1.a, methane tends to be higher in return tunnels than in intake tunnels. Main tunnels are either intakes or returns with some areas being neutral. The methane levels in a neutral area should be low unless the area is open to a return tunnel, there is a leak of return air into the area, or there is some other methane source in the area. Likewise, permanent mine installations (such as underground storage areas, rest or waiting areas for mine workers, control/communications centers, coal loading areas, electric service panels, booster fans, and so on) can be in or adjoining either intakes or returns or possibly neutral areas with the quality of air being so determined. The likelihood for this event depends on the type of air in the tunnel or installation. In a quantified model, there would have to be separate branches for these areas, one for intakes, one for returns, and perhaps one for neutral areas if they exist. Additional branches would be required if there were tunnels or installations with different hazards present (such as tunnels with coal conveyors and those without).

  b) Airborne coal dust should not be a problem in main tunnel or at a permanent installations, with the possible exception of points where coal is transferred between conveyor belts or loaded into mine cars or hoppers.

c) See comment 1.1.2.2.1.1.c

- 2.2.2.1.2 ->
  Explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 2.2.2.1.2
> Explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

OR (exclusive)

- 2.2.2.1.2.1 ->
  Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).
- 2.2.2.1.2.2 ->
  Mine is evacuated and explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 2.2.2.1.2.1
> Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.1.2.1.1 *
  Mine is not evacuated (given that an explosive mixture of methane and/or airborne coal dust is present in a main tunnel or at a permanent installation).

  a) This event is the logical negative of 2.2.2.1.2.2.1.

- 2.2.2.1.2.1.2 ->
  Explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that such a mixture is present in the area, that the mine is not evacuated and that there is no ongoing fire anywhere in the mine).

> 2.2.2.1.2.2
> Mine is evacuated and explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.1.2.2.1 *
  Mine is evacuated (given that an explosive mixture of methane and/or coal-dust is present in a main tunnel or at a permanent installation).

  a) See comment 1.2.2.2.1.2.2.1.a.

  b) This event is the logical negative of 2.2.2.1.2.1.1.

- 2.2.2.1.2.2.2 *
  Explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point

(given that such a mixture is present in the area, that mine is evacuated and that there is no ongoing fire anywhere in the mine).

a) See comment 1.1.2.2.1.2.2.2.a.

> 2.2.2.1.2.1.2
Explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation is raised to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.1.2.1.2.1 ->
  A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 2.2.2.1.2.1.2.2 ->
  Heat (without flame or spark) raises an explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

> 2.2.2.1.2.1.2.1
A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.1.2.1.2.1.1 ->
  A spark or open flame reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 2.2.2.1.2.1.2.1.2 *
  An explosive mixture of methane and/or airborne coal dust in the main tunnel or at a permanent installation is raised to its ignition point by a spark or open flame (given that a point in the area where such a mixture exists has been reached by a spark or open flame).

  a) See comment 1.1.2.2.1.2.1.2.1.2.a.

> 2.2.2.1.2.1.2.2
Heat (without flame or spark) raises an explosive mixture of methane and/or airborne coal dust in a main tunnel or at a permanent installation to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.1.2.1.2.2.1 ->
  Heat energy (without spark or flame) reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 2.2.2.1.2.1.2.2.2 *
  An explosive mixture of methane and/or airborne coal dust in a main

tunnel or at a permanent installation is raised to its ignition point by heat without a spark or flame (given that heat energy reaches a point in the area where such a mixture exists).

a) See comment 1.1.2.2.1.2.1.2.2.2.a.

> 2.2.2.1.2.1.2.1.1
A spark or open flame reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.1.2.1.2.1.1.1 ->
Coal cutting, rock cutting or drilling operation causes a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.1.1.2 ->
Shooting operation causes a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.1.1.3 ->
Operation of electrical equipment causes a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.1.1.4 ->
Operation of combustion equipment produces a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.1.1.5 ->
Operation of mechanical equipment produces a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.1.1.6 ->
Use of contraband or other fire hazard causes a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

> 2.2.2.1.2.1.2.2.1
Heat energy (without spark or flame) reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.1.2.1.2.2.1.1 ->
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.2.1.2 ->
  Shooting operation causes causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.2.1.3 ->
  Operation of electrical equipment causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 2.2.2.1.2.1.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

> 2.2.2.1.2.1.2.1.1.1
Coal cutting, rock cutting or drilling operation causes a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.1.1.1.1 *
  Coal cutting rock cutting or drilling operation is being performed in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

  a) See comment 1.2.2.2.1.2.1.2.1.1.1.1.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 2.2.2.1.2.1.2.1.1.1.2 *
  Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such an operation is being performed in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a.

  b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.1.1.1.3 *
  Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of a main tunnel or permanent installation reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) As explained in comment 1.1.2.2.1.2.1.2.1.1.1.3.b, methane and airborne coal dust concentrations may vary from spot to spot in an area. In a main tunnel or permanent installation, this variability should be less evident. Methane will still tend to collect in roof cavities. A particular hazard in the return tunnels is the point or points where the methane drainage system is vented into the return air.

> 2.2.2.1.2.1.2.1.1.2
Shooting operation causes a spark or open flame which reaches a point in a main tunnel or at a permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.1.1.2.1 *
Shooting operation is being performed in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

  a) See comment 1.2.2.2.1.2.1.2.1.1.2.1.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 2.2.2.1.2.1.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the main tunnel or permanent installation (given that such an operation is being performed in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

  b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of a main tunnel or permanent installation reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

> 2.2.2.1.2.1.2.1.1.3
Operation of electrical equipment causes a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

  a) See comments 1.2.2.2.1.2.1.2.1.1.3.1.a and 1.3.2.2.1.2.1.2.1.1.3.1.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 2.2.2.1.2.1.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.3.2.a.

  b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.1.1.3.3 *

Spark or open flame caused by operation of electrical equipment in the vicinity of a main tunnel or permanent installation reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

> 2.2.2.1.2.1.2.1.1.4
Operation of combustion equipment produces a spark or open flame which reaches a point in a main tunnel or permanent installation here an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

a) See comments 1.2.2.2.1.2.1.2.1.1.4.1.a and 1.3.2.2.1.2.1.2.1.1.4.1.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 2.2.2.1.2.1.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.4.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

> 2.2.2.1.2.1.2.1.1.5
Operation of mechanical equipment produces a spark or open flame which reaches a point in a main tunnel or permanent installation here an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

a) See comment 1.1.2.2.1.2.1.2.1.1.5.1.a. The use of equipment in main return tunnel or permanent installations is generally not as restricted as for panel return tunnel or permanent installations. Thus, the two types of tunnel or permanent installations are fairly similar with respect to mechanical equipment. There there could be mine cars and locomotives (electric or diesel driven), conveyors, coal loaders, and other pieces of large and small mechanical equipment.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 2.2.2.1.2.1.2.1.1.5.2 *
  Operation of mechanical equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.5.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.1.1.5.3 *
  Spark or open flame caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

    b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

> 2.2.2.1.2.1.2.1.1.6
> Use of contraband or other fire hazard causes a spark or open flame which reaches a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.1.1.6.1 *
  Use of contraband or other fire hazard occurs in the vicinity of the main tunnel or permanent installation (given that the mine has not been evacuated).

    a) See comment 1.1.2.2.1.2.1.2.1.1.6.1.a.

    b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 2.2.2.1.2.1.2.1.1.6.2 *
  Use of contraband or other fire hazard causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such use or hazard occurs in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.6.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.1.1.6.3 *
  Spark or open flame caused by use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

    b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

    c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 2.2.2.1.2.1.2.2.1.1
> Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operation is being performed in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

    a) This event is identical to event 2.2.2.1.2.1.2.1.1.1.1.

- 2.2.2.1.2.1.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the main tunnel or permanent installation causes heat energy to be produced (given that such an operation is being performed in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of a main tunnel or permanent installation to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 2.2.2.1.2.1.2.2.1.1.4 *
Enough heat energy (without spark or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of a main tunnel or permanent installation reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

> 2.2.2.1.2.1.2.2.1.2
Shooting operation causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

    a) This event is identical to 2.2.2.1.2.1.2.1.1.2.1

- 2.2.2.1.2.1.2.2.1.2.2 *
Shooting operation in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such an operation is being performed in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of a main tunnel or permanent installation to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 2.2.2.1.2.1.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of the a main tunnel or permanent installation reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

  b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

  c) See comment 1.1.2.2.1.2.1.2.1.1.2.3.b.

> 2.2.2.1.2.1.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

  a) This event is identical to 2.2.2.1.2.1.2.1.1.3.1

- 2.2.2.1.2.1.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.3.2.a.

  b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of the a main tunnel or permanent installation to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 2.2.2.1.2.1.2.2.1.3.4 *
Enough heat energy (without spark or flame) caused by operation of electrical equipment in the vicinity of the a main tunnel or permanent installation reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

  b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

> 2.2.2.1.2.1.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.2.1.4.1 *
  Combustion equipment is operating in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

    a) This event is identical to 2.2.2.1.2.1.2.1.1.4.1

- 2.2.2.1.2.1.2.2.1.4.2 *
  Operation of combustion equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.4.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.2.1.4.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 2.2.2.1.2.1.2.2.1.4.4 *
  Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

> 2.2.2.1.2.1.2.2.1.5
> Operation of mechanical equipment causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.2.1.5.1 *
  Mechanical equipment is operating in the vicinity of a main tunnel or permanent installation (given that the mine has not been evacuated).

    a) This event is identical to 2.2.2.1.2.1.2.1.1.5.1

- 2.2.2.1.2.1.2.2.1.5.2 *
  Operation of mechanical equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.5.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.2.1.5.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 2.2.2.1.2.1.2.2.1.5.4 *
  Enough heat energy (without spark or flame) caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation reaches a point in that area where an explosive mixture

of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

> 2.2.2.1.2.1.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) to reach a point in a main tunnel or permanent installation where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 2.2.2.1.2.1.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the main tunnel or permanent installation (given that the mine has not been evacuated).

a) This event is identical to 2.2.2.1.2.1.2.1.1.6.1

- 2.2.2.1.2.1.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

a) This might occur under much the same circumstances as 2.2.2.1.2.1.2.1.1.6.2.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 2.2.2.1.2.1.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 2.2.2.1.2.1.2.2.1.6.4 *
Enough heat energy (without spark or flame) caused by use of contraband or other fire hazard in the vicinity of the a main tunnel or permanent installation reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 2.2.2.1.2.1.2.1.1.1.3.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 2.2.2.2
Loose coal or accumulated coal dust in a main tunnel or permanent installation is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.2.1 *
Presence of loose coal or accumulated coal dust in a main tunnel or permanent installation.

a) See comment 1.1.2.2.2.1.a.

- 2.2.2.2.2 ->
Loose coal or accumulated coal dust in a main tunnel or permanent installation is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 2.2.2.2.2
Loose coal or accumulated coal dust in a main tunnel or permanent installation is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.2.2.1 ->
A spark or open flame raises loose coal or accumulated coal dust in a main tunnel or permanent installation to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 2.2.2.2.2.2 ->
Heat (without flame or spark) raises loose coal or accumulated coal dust in a main tunnel or permanent installation to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 2.2.2.2.2.3 *
Spontaneous combustion of loose coal or accumulated coal dust in a main tunnel or permanent installation (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

a) See comment 1.1.2.2.2.3.a.

> 2.2.2.2.2.1
A spark or open flame raises loose coal or accumulated coal dust in a main tunnel or permanent installation to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.2.2.1.1 ->
A spark or open flame comes in contact with loose coal or accumulated coal dust in a main tunnel or permanent installation (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 2.2.2.2.2.1.2 *
Loose coal or accumulated coal dust in a main tunnel or permanent installation is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

a) See comment 1.1.2.2.2.2.1.2.a.

b) See comment 1.1.2.2.2.2.1.2.b.

> 2.2.2.2.2.2
Heat (without flame or spark) raises loose coal or accumulated coal dust in a main tunnel or permanent installation to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.2.2.2.1 ->
Heat energy (without spark or flame) reaches a point in a main tunnel

or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 2.2.2.2.2.2.2 *
  Loose coal or accumulated coal dust in a main tunnel or permanent installation is raised to its ignition point by heat energy (without spark or flame) (given that heat energy reaches a point in the area where such material exists).

  a) See comment 1.1.2.2.2.2.2.2.a.

  b) See comment 1.1.2.2.2.2.1.2.b.

> 2.2.2.2.2.1.1
A spark or open flame comes in contact with loose coal or accumulated coal dust in a main tunnel or permanent installation (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.2.2.1.1.1 ->
  Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in a main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.2.2.1.1.2 ->
  Shooting operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in a main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.2.2.1.1.3 ->
  Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.2.2.1.1.4 ->
  Operation of combustion equipment produces a spark or open flame which comes in contact with loose coal or accumulated coal dust in the main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.2.2.1.1.5 ->
  Operation of mechanical equipment produces a spark or open flame which comes in contact with loose coal or accumulated coal dust in the main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.2.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the main tunnel or permanent installation (given that such material is present in in the area).

> 2.2.2.2.2.2.1
Heat energy (without spark or flame) reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.2.2.2.1.1 ->
  Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 2.2.2.2.2.2.1.2 ->

Shooting operation causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 2.2.2.2.2.2.1.3 ->
  Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 2.2.2.2.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 2.2.2.2.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 2.2.2.2.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

> 2.2.2.2.2.1.1.1
> Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in a main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.2.2.1.1.1.1 *
  Coal cutting, rock cutting or drilling operation is being performed in the vicinity of a main tunnel or permanent installation.

  a) This event is identical to event 2.2.2.1.2.1.2.1.1.1.1.

- 2.2.2.2.2.1.1.1.2 *
  Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 2.2.2.1.2.1.2.1.1.1.2.

- 2.2.2.2.2.1.1.1.3 *
  Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of a main tunnel or permanent installation comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.2.2.1.1.2
> Shooting operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in a main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.2.2.1.1.2.1 *
  Shooting operation is being performed in the vicinity of a main tunnel or permanent installation.

  a) This event is identical to event 2.2.2.1.2.1.2.1.1.2.1.

- 2.2.2.2.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the main tunnel or permanent installation (given that such an operation is being performed in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.1.1.2.2.

- 2.2.2.2.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of a main tunnel or permanent installation comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.2.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.2.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.3.1.

- 2.2.2.2.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.1.1.3.2.

- 2.2.2.2.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of a main tunnel or permanent installation comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.2.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.2.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.4.1.

- 2.2.2.2.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.1.1.4.2.

- 2.2.2.2.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation comes in contact with loose coal or accumulated coal dust in the area (given that such

material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.2.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.2.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.5.1.

- 2.2.2.2.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.1.1.5.2.

- 2.2.2.2.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.2.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the main tunnel or permanent installation (given that such material is present in in the area).

AND

- 2.2.2.2.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.6.1.

- 2.2.2.2.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such use or hazard occurs in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.1.1.6.2.

- 2.2.2.2.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 2.2.2.2.2.2.1.1
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in a main tunnel or

permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 2.2.2.2.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operation is being being performed in the vicinity of a main tunnel or permanent installation.

    a) This event is identical to event 2.2.2.1.2.1.2.1.1.1.1.

- 2.2.2.2.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the main tunnel or permanent installation causes heat energy to be produced (given that such an operation is being performed in the vicinity).

    a) This event is identical to event 2.2.2.1.2.1.2.2.1.1.2.

- 2.2.2.2.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting, or drilling operations in the vicinity of a main tunnel or permanent installation to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.2.2.2.1.1.3.a.

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.2.2.2.1.1.4 *
Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting, or drilling operations in the vicinity of a main tunnel or permanent installation reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.2.2.2.1.2
Shooting operation causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 2.2.2.2.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of a main tunnel or permanent installation.

    a) This event is identical to event 2.2.2.1.2.1.2.1.1.2.1.

- 2.2.2.2.2.2.1.2.2 *
Shooting operation in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such an operation is being performed in the vicinity).

    a) This event is identical to event 2.2.2.1.2.1.2.2.1.2.2.

- 2.2.2.2.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of a main tunnel or permanent installation to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.2.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.2.2.2.1.2.4 *

Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of a main tunnel or permanent installation reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.2.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 2.2.2.2.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.3.1.

- 2.2.2.2.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.2.1.3.2.

- 2.2.2.2.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of a main tunnel or permanent installation to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.2.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of a main tunnel or permanent installation reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.2.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 2.2.2.2.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.4.1.

- 2.2.2.2.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.2.1.4.2.

- 2.2.2.2.2.2.1.4.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.2.2.2.1.4.4 *
  Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.2.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 2.2.2.2.2.2.1.5.1 *
  Mechanical equipment is operating in the vicinity of a main tunnel or permanent installation.

  a) This event is identical to event 2.2.2.1.2.1.2.1.1.5.1.

- 2.2.2.2.2.2.1.5.2 *
  Operation of mechanical equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 2.2.2.1.2.1.2.2.1.5.2.

- 2.2.2.2.2.2.1.5.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.2.2.2.1.5.4 *
  Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.2.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 2.2.2.2.2.2.1.6.1 *

Use of contraband or other fire hazard occurs in the vicinity of the main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.6.1.

- 2.2.2.2.2.2.1.6.2 *
  Use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

  a) This event is identical to event 2.2.2.1.2.1.2.2.1.6.2.

- 2.2.2.2.2.2.1.6.3 *
  Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.2.2.2.1.6.4 *
  Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 2.2.2.3
An imported flammable material in a main tunnel or permanent installation is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.3.1 *
  Presence of an imported flammable material in structures, in equipment, or lying loose main tunnel or permanent installation.

  a) See comments 1.1.2.2.3.1.a, b & c.

- 2.2.2.3.2 ->
  An imported flammable material in a main tunnel or permanent installation is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 2.2.2.3.2
An imported flammable material in a main tunnel or permanent installation is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.3.2.1 ->
  A spark or open flame raises an imported flammable material in the main tunnel or permanent installation to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 2.2.2.3.2.2 ->
  Heat (without flame or spark) raises an imported flammable material in a main tunnel or permanent installation to its ignition point (given

that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 2.2.2.3.2.3 *
  Spontaneous combustion of an imported flammable material in a main tunnel or permanent installation (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.2.2.2.2.3.a.

> 2.2.2.3.2.1
A spark or open flame raises an imported flammable material in the main tunnel or permanent installation to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.3.2.1.1 ->
  A spark or open flame comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).
- 2.2.2.3.2.1.2 *
  An imported flammable material in a main tunnel or permanent installation is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

  a) See comment 1.1.2.2.2.2.1.2.a.

  b) See comment 1.1.2.2.3.2.1.2.b.

> 2.2.2.3.2.2
Heat (without flame or spark) raises an imported flammable material in a main tunnel or permanent installation to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 2.2.2.3.2.2.1 ->
  Heat energy (without spark or flame) reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).
- 2.2.2.3.2.2.2 *
  An imported flammable material in a main tunnel or permanent installation is raised to its ignition point by heat without spark or flame (given that heat energy reaches a point in the area where such material exists).

  a) See comment 1.1.2.2.2.2.2.2.a.

  b) See comment 1.1.2.2.3.2.1.2.b.

> 2.2.2.3.2.1.1
A spark or open flame comes in contact with an imported flammable material in a main tunnel or permanent installation (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.3.2.1.1.1 ->
  Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with an imported flammable material

in a main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.3.2.1.1.2 ->
  Shooting operation causes a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.3.2.1.1.3 ->
  Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.3.2.1.1.4 ->
  Operation of combustion equipment produces a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.3.2.1.1.5 ->
  Operation of mechanical equipment produces a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

- 2.2.2.3.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the main tunnel or permanent installation (given that such material is present in the area).

> 2.2.2.3.2.2.1
Heat energy (without spark or flame) reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 2.2.2.3.2.2.1.1 ->
  Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

- 2.2.2.3.2.2.1.2 ->
  Shooting operation causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

- 2.2.2.3.2.2.1.3 ->
  Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

- 2.2.2.3.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

- 2.2.2.3.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

- 2.2.2.3.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that

such material is present in the area).

> 2.2.2.3.2.1.1.1
Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.3.2.1.1.1.1 *
Coal cutting, rock cutting or drilling operation is being performed in the vicinity of a main tunnel or permanent installation.

  a) This event is identical to event 2.2.2.1.2.1.2.1.1.1.1.

- 2.2.2.3.2.1.1.1.2 *
Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 2.2.2.1.2.1.2.1.1.1.2.

- 2.2.2.3.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of a main tunnel or permanent installation comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.3.2.1.1.2
Shooting operation causes a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.3.2.1.1.2.1 *
Shooting operation is being performed in the vicinity of a main tunnel or permanent installation.

  a) This event is identical to event 2.2.2.1.2.1.2.1.1.2.1.

- 2.2.2.3.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the main tunnel or permanent installation (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 2.2.2.1.2.1.2.1.1.2.2.

- 2.2.2.3.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of a main tunnel or permanent installation comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.3.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.3.2.1.1.3.1 *

Electrical equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.3.1.

- 2.2.2.3.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.1.1.3.2.

- 2.2.2.3.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of a main tunnel or permanent installation comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.3.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.3.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.4.1.

- 2.2.2.3.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.1.1.4.2.

- 2.2.2.3.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.3.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with an imported flammable material in a main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.3.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.5.1.

- 2.2.2.3.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.1.1.5.2.

- 2.2.2.3.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 2.2.2.3.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the main tunnel or permanent installation (given that such material is present in the area).

AND

- 2.2.2.3.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the main tunnel or permanent installation.

    a) This event is identical to event 2.2.2.1.2.1.2.1.1.6.1.

- 2.2.2.3.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of a main tunnel or permanent installation (given that such use or hazard occurs in the vicinity).

    a) This event is identical to event 2.2.2.1.2.1.2.1.1.6.2.

- 2.2.2.3.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

    b) See comment 1.1.2.2.1.2.1.2.1.1.1.3.c.

> 2.2.2.3.2.2.1.1
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

AND

- 2.2.2.3.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operation is being being performed in the vicinity of a main tunnel or permanent installation.

    a) This event is identical to event 2.2.2.1.2.1.2.1.1.1.1.

- 2.2.2.3.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the main tunnel or permanent installation causes heat energy to be produced (given that such an operation is being performed in the vicinity).

    a) This event is identical to event 2.2.2.1.2.1.2.2.1.1.2.

- 2.2.2.3.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of a main tunnel or permanent installation to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.3.2.2.1.1.4 *
Enough heat energy (without sparks or flame) caused by coalcutting, rock cutting or drilling operations in the vicinity of a main tunnel or permanent installation reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.3.2.2.1.2
Shooting operation causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

AND

- 2.2.2.3.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.2.1.

- 2.2.2.3.2.2.1.2.2 *
Shooting operation in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.2.1.2.2.

- 2.2.2.3.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of a main tunnel or permanent installation to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.3.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of a main tunnel or permanent installation reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.3.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

AND

- 2.2.2.3.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.3.1.

- 2.2.2.3.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.2.1.3.2.

- 2.2.2.3.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of a main tunnel or permanent installation to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.3.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of a main tunnel or permanent installation reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.3.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

AND

- 2.2.2.3.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of a main tunnel or permanent installation.

a) This event is identical to event 2.2.2.1.2.1.2.1.1.4.1.

- 2.2.2.3.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 2.2.2.1.2.1.2.2.1.4.2.

- 2.2.2.3.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.3.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of a main tunnel or permanent installation reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.3.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

AND

- 2.2.2.3.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of a main tunnel or permanent installation.

    a) This event is identical to event 2.2.2.1.2.1.2.1.1.5.1.

- 2.2.2.3.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) This event is identical to event 2.2.2.1.2.1.2.2.1.5.2.

- 2.2.2.3.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.3.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.3.2.2.1.5.4 *
Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in the vicinity of a main tunnel or permanent installation reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 2.2.2.3.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in a main tunnel or permanent installation where an imported flammable material exists (given that such material is present in the area).

AND

- 2.2.2.3.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the main tunnel or permanent installation.

    a) This event is identical to event 2.2.2.1.2.1.2.1.1.6.1.

- 2.2.2.3.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

    a) This event is identical to event 2.2.2.1.2.1.2.2.1.6.2.

- 2.2.2.3.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.3.2.2.1.1.3.a

    b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 2.2.2.3.2.2.1.6.4 *
Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of a main tunnel or permanent installation reaches a point in that area where imported flammable material exists to raise the material to its ignition point

(given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 3
Initiation of fire in a developing area (given that there is no ongoing fire anywhere in the mine).

OR

- 3.1 ->
Initiation of fire by spontaneous combustion of coal in the seam at a developing area (given that there is no ongoing fire anywhere in the mine).

- 3.2 ->
Ignition of combustible material in a developing area (given that there is no ongoing fire anywhere in the mine).

> 3.1
Initiation of fire by spontaneous combustion of coal in the seam at a developing area (given that there is no ongoing fire anywhere in the mine).

AND

- 3.1.1 *
Presence of coal prone to spontaneous combustion in the seam at a developing area.

    a) See comment 1.1.1.1.a.

    b) Developing areas include new panels, new main tunnels and new service and special purpose areas. In the case of new panels, two parallel tunnels are cut into the seam and then joined by a tunnel cut across the seam which will become the face. In the advance method, the tunnels are developed to their mininmum length before active mining is begun. In the retreat method, the tunnels are developed to their maximum length. In either case, the presence of coal in the seam is assured (the event thus depends on whether the coal is prone to self-heating or not). Main tunnels or other areas are often developed in the seam but might also be cut into rock.

- 3.1.2 *
Sufficiently high temperatures are maintained for long enough in the seam at a developing area that would produce spontaneous combustion if no heat were dissipated by air flow (given the type of coal in the seam and that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.1.2.a.

- 3.1.3 *
There is an air-flow through the seam at a developing area permitting enough oxygen in contact with the coal to allow spontaneous combustion (given that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.1.3.a.

- 3.1.4 *
The flow of air through the seam at a developing area does not dissipate enough heat to prevent spontaneous combustion (given that the temperature maintained in the seam is high enough in the absence of such dissipation to produce such a spontaneous combustion, that there is enough air-flow in the seam to provide the required oxygen and that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.1.4.a.

> 3.2
Ignition of a combustible material in a developing area (given that there is no ongoing fire anywhere in the mine).

AND

- 3.2.1 *
  Level of oxygen in the air in a developing area is sufficient to allow combustion (given that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.2.1.a.

- 3.2.2 ->
  A combustible material in a developing area is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 3.2.2
  A combustible material in a developing area is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

  OR

- 3.2.2.1 ->
  Explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

- 3.2.2.2 ->
  Loose coal or accumulated coal dust in a developing area is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

- 3.2.2.3 ->
  An imported flammable material in a developing area is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

> 3.2.2.1
  Explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

  AND

- 3.2.2.1.1 *
  Presence of an explosive mixture of methane and/or airborne coal dust in a developing area (given that the level of oxygen in the area is sufficiently high for combustion).

    a) Because of development of tunnels tends to take place along the seam, there is a considerable likelihood of significant amounts of methane being released. Also the ventilation is augmented or maintained by portable blowers and similar equipment. These temporary measures may not always be as effective as they should be in controlling the level of methane in the air.

    b) As with methane, coal dust levels should also be high in these areas.

    c) See comment 1.1.2.2.1.1.c

- 3.2.2.1.2 ->
  Explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 3.2.2.1.2

Explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

OR (exclusive)

- 3.2.2.1.2.1 ->
Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.1.2.2 ->
Mine is evacuated and explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

> 3.2.2.1.2.1
Mine is not evacuated and explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.1.2.1.1 *
Mine is not evacuated (given that an explosive mixture of methane and/or airborne coal dust is present in a developing area).

    a) This event is the logical negative of 3.2.2.1.2.2.1.

- 3.2.2.1.2.1.2 ->
Explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area, that the mine is not evacuated and that there is no ongoing fire anywhere in the mine).

> 3.2.2.1.2.2
Mine is evacuated and explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.1.2.2.1 *
Mine is evacuated (given that an explosive mixture of methane and/or coal-dust is present in a developing area).

    a) See comment 1.2.2.2.1.2.2.1.a.

    b) This event is the logical negative of 3.2.2.1.2.1.1.

- 3.2.2.1.2.2.2 *
Explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area, that mine is evacuated and that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.2.2.1.2.2.2.a.

> 3.2.2.1.2.1.2
Explosive mixture of methane and/or airborne coal dust in a developing area is raised to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 3.2.2.1.2.1.2.1 ->
  A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in a developing area to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 3.2.2.1.2.1.2.2 ->
  Heat (without flame or spark) raises an explosive mixture of methane and/or airborne coal dust in a developing area to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

> 3.2.2.1.2.1.2.1
A spark or open flame raises an explosive mixture of methane and/or airborne coal dust in a developing area to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.1.2.1.2.1.1 ->
  A spark or open flame reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 3.2.2.1.2.1.2.1.2 *
  An explosive mixture of methane and/or airborne coal dust in the developing area is raised to its ignition point by a spark or open flame (given that a point in the area where such a mixture exists has been reached by a spark or open flame).

  a) See comment 1.1.2.2.1.2.1.2.1.2.a.

> 3.2.2.1.2.1.2.2
Heat (without flame or spark) raises an explosive mixture of methane and/or airborne coal dust in a developing area to its ignition point (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.1.2.1.2.2.1 ->
  Heat energy (without spark or flame) reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

- 3.2.2.1.2.1.2.2.2 *
  An explosive mixture of methane and/or airborne coal dust in the developing area is raised to its ignition point by heat without a spark or flame (given that heat energy reaches a point in the area where such a mixture exists).

  a) See comment 1.1.2.2.1.2.1.2.2.2.a.

> 3.2.2.1.2.1.2.1.1
A spark or open flame reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).

OR

- 3.2.2.1.2.1.2.1.1.1 ->
  Coal cutting, rock cutting or drilling operation causes a spark or

open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.1.1.2 ->
  Shooting operation causes a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.1.1.3 ->
  Operation of electrical equipment causes a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.1.1.4 ->
  Operation of combustion equipment produces a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.1.1.5 ->
  Operation of mechanical equipment produces a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

> 3.2.2.1.2.1.2.2.1
> Heat energy (without spark or flame) reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area, that the mine has not been evacuated and that there is no ongoing fire anywhere in the mine).
>
> OR

- 3.2.2.1.2.1.2.2.1.1 ->
  Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.2.1.2 ->
  Shooting operation causes causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.2.1.3 ->
  Operation of electrical equipment causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) to reach a point in a developing area where an explosive

mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

- 3.2.2.1.2.1.2.2.1.6 ->
Use of contraband or other fire hazard causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

> 3.2.2.1.2.1.2.1.1.1
Coal cutting, rock cutting or drilling operation causes a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.1.1.1.1 *
Coal cutting rock cutting or drilling operation is being performed in the vicinity of a developing area (given that the mine has not been evacuated).

    a) See comment 1.2.2.2.1.2.1.2.1.1.1.1.a. These operations are of course quite regular in a developing area.

    b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 3.2.2.1.2.1.2.1.1.1.2 *
Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of a developing area (given that such an operation is being performed in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a. Because the material being cut or drilled is often rock, there is a higher probability of incendive sparks than at the face.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of a developing area reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

    b) As explained in comment 1.1.2.2.1.2.1.2.1.1.1.3.b, methane and airborne coal dust concentrations may vary from spot to spot in an area. In a developing area, there may be many roof cavities for methane to collect in and the ventilation system may not be as effective in removing the gas from all parts of the area. Also, these areas can be reletively small and confined increasing the probability of this particular event.

> 3.2.2.1.2.1.2.1.1.2
Shooting operation causes a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.1.1.2.1 *
Shooting operation is being performed in the vicinity of a developing area (given that the mine has not been evacuated).

    a) See comment 1.2.2.2.1.2.1.2.1.1.2.1. Shooting operations are required fairly frequently in developing areas.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 3.2.2.1.2.1.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the developing area (given that such an operation is being performed in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of a developing area reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

> 3.2.2.1.2.1.2.1.1.3
Operation of electrical equipment causes a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of a developing area (given that the mine has not been evacuated).

a) See comments 1.2.2.2.1.2.1.2.1.1.3.1.a and 1.3.2.2.1.2.1.2.1.1.3.1.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 3.2.2.1.2.1.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.3.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of a developing area reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

> 3.2.2.1.2.1.2.1.1.4
Operation of combustion equipment produces a spark or open flame which reaches a point in a developing area here an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of a developing area (given that the mine has not been evacuated).

a) See comments 1.2.2.2.1.2.1.2.1.1.4.1.a and 1.3.2.2.1.2.1.2.1.1.4.1.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 3.2.2.1.2.1.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.4.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of a developing area reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

> 3.2.2.1.2.1.2.1.1.5
Operation of mechanical equipment produces a spark or open flame which reaches a point in a developing area here an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of a developing area (given that the mine has not been evacuated).

a) See comment 1.1.2.2.1.2.1.2.1.1.5.1.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 3.2.2.1.2.1.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.5.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of a developing area reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

> 3.2.2.1.2.1.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which reaches a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the

developing area (given that the mine has not been evacuated).

a) See comment 1.1.2.2.1.2.1.2.1.1.6.1.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.1.1.d.

- 3.2.2.1.2.1.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of a developing area (given that such use or hazard occurs in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.6.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of a developing area reaches a point in the area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 3.2.2.1.2.1.2.2.1.1
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operation is being performed in the vicinity of a developing area (given that the mine has not been evacuated).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.1.1.

- 3.2.2.1.2.1.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the developing area causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of a developing area to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 3.2.2.1.2.1.2.2.1.1.4 *
Enough heat energy (without spark or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of a developing area reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

> 3.2.2.1.2.1.2.2.1.2
Shooting operation causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of a developing area (given that the mine has not been evacuated).

    a) This event is identical to 3.2.2.1.2.1.2.1.1.2.1

- 3.2.2.1.2.1.2.2.1.2.2 *
Shooting operation in the vicinity of a developing area causes heat energy to be produced (given that such an operation is being performed in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.2.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of a developing area to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

    a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 3.2.2.1.2.1.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of a developing area reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such operations in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

    b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

    c) See comment 1.1.2.2.1.2.1.2.1.1.2.3.b.

> 3.2.2.1.2.1.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of a developing area (given that the mine has not been evacuated).

    a) This event is identical to 3.2.2.1.2.1.2.1.1.3.1

- 3.2.2.1.2.1.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.2.1.3.2.a.

    b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.2.1.3.3 *

Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of a developing area to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 3.2.2.1.2.1.2.2.1.3.4 *
Enough heat energy (without spark or flame) caused by operation of electrical equipment in the vicinity of a developing area reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

> 3.2.2.1.2.1.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of a developing area (given that the mine has not been evacuated).

a) This event is identical to 3.2.2.1.2.1.2.1.1.4.1

- 3.2.2.1.2.1.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.4.2.a.

b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of a developing area to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 3.2.2.1.2.1.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of a developing area reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

> 3.2.2.1.2.1.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.2.1.5.1 *
  Mechanical equipment is operating in the vicinity of a developing area (given that the mine has not been evacuated).

  a) This event is identical to 3.2.2.1.2.1.2.1.1.5.1

- 3.2.2.1.2.1.2.2.1.5.2 *
  Operation of mechanical equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.5.2.a.

  b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.2.1.5.3 *
  Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of a developing area to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 3.2.2.1.2.1.2.2.1.5.4 *
  Enough heat energy (without spark or flame) caused by operation of mechanical equipment in the vicinity of a developing area reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

  b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

> 3.2.2.1.2.1.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) to reach a point in a developing area where an explosive mixture of methane and/or airborne coal dust exists (given that such a mixture is present in the area and that the mine has not been evacuated).

AND

- 3.2.2.1.2.1.2.2.1.6.1 *
  Use of contraband or other fire hazard occurs in the vicinity of the developing area (given that the mine has not been evacuated).

  a) This event is identical to 3.2.2.1.2.1.2.1.1.6.1

- 3.2.2.1.2.1.2.2.1.6.2 *
  Use of contraband or other fire hazard in the vicinity of a developing area causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

  a) This might occur under much the same circumstances as 3.2.2.1.2.1.2.1.1.6.2.

  b) See comment 1.2.2.2.1.2.1.2.1.1.1.2.b.

- 3.2.2.1.2.1.2.2.1.6.3 *
  Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of a developing area to raise an explosive mixture of methane and/or airborne coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comments 1.1.2.2.1.2.1.2.2.1.1.3.a & b.

- 3.2.2.1.2.1.2.2.1.6.4 *
  Enough heat energy (without spark or flame) caused by use of

contraband or other fire hazard in the vicinity of a developing area reaches a point in that area where an explosive mixture of methane and/or airborne coal dust exists to raise the mixture to its ignition point (given that such a mixture is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a.

b) See comment 3.2.2.1.2.1.2.1.1.1.3.b.

c) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 3.2.2.2
Loose coal or accumulated coal dust in a developing area is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.2.1 *
Presence of loose coal or accumulated coal dust in a developing area.

a) See comment 1.1.2.2.2.1.a. As with methane and airborne coal dust, there will tend to be both acummulations of coal dust and larger peices of coal in the area due to the development activity.

- 3.2.2.2.2 ->
Loose coal or accumulated coal dust in a developing area is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 3.2.2.2.2
Loose coal or accumulated coal dust in a developing area is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 3.2.2.2.2.1 ->
A spark or open flame raises loose coal or accumulated coal dust in a developing area to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.2.2.2 ->
Heat (without flame or spark) raises loose coal or accumulated coal dust in a developing area to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.2.2.3 *
Spontaneous combustion of loose coal or accumulated coal dust in a developing area (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

a) See comment 1.1.2.2.2.3.a.

> 3.2.2.2.2.1
A spark or open flame raises loose coal or accumulated coal dust in a developing area to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.2.2.1.1 ->
A spark or open flame comes in contact with loose coal or accumulated

coal dust in a developing area (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.2.2.1.2 *
Loose coal or accumulated coal dust in a developing area is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

    a) See comment 1.1.2.2.2.2.1.2.a.

    b) See comment 1.1.2.2.2.2.1.2.b.

> 3.2.2.2.2.2
Heat (without flame or spark) raises loose coal or accumulated coal dust in a developing area to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.2.2.2.1 ->
Heat energy (without spark or flame) reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.2.2.2.2 *
Loose coal or accumulated coal dust in a developing area is raised to its ignition point by heat energy (without spark or flame) (given that heat energy reaches a point in the area where such material exists).

    a) See comment 1.1.2.2.2.2.2.2.a.

    b) See comment 1.1.2.2.2.2.1.2.b.

> 3.2.2.2.2.1.1
A spark or open flame comes in contact with loose coal or accumulated coal dust in a developing area (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 3.2.2.2.2.1.1.1 ->
Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in a developing area (given that such material is present in the area).

- 3.2.2.2.2.1.1.2 ->
Shooting operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in a developing area (given that such material is present in the area).

- 3.2.2.2.2.1.1.3 ->
Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the developing area (given that such material is present in the area).

- 3.2.2.2.2.1.1.4 ->
Operation of combustion equipment produces a spark or open flame which comes in contact with loose coal or accumulated coal dust in the developing area (given that such material is present in the area).

- 3.2.2.2.2.1.1.5 ->
Operation of mechanical equipment produces a spark or open flame which comes in contact with loose coal or accumulated coal dust in the developing area (given that such material is present in the area).

- 3.2.2.2.2.1.1.6 ->
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the

developing area (given that such material is present in in the area).

> 3.2.2.2.2.2.1
Heat energy (without spark or flame) reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 3.2.2.2.2.2.1.1 ->
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 3.2.2.2.2.2.1.2 ->
Shooting operation causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 3.2.2.2.2.2.1.3 ->
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 3.2.2.2.2.2.1.4 ->
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 3.2.2.2.2.2.1.5 ->
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

- 3.2.2.2.2.2.1.6 ->
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

> 3.2.2.2.2.1.1.1
Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in a developing area (given that such material is present in the area).

AND

- 3.2.2.2.2.1.1.1.1 *
Coal cutting, rock cutting or drilling operation is being performed in the vicinity of a developing area.

  a) This event is identical to event 3.2.2.1.2.1.2.1.1.1.1.

- 3.2.2.2.2.1.1.1.2 *
Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of a developing area (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 3.2.2.1.2.1.2.1.1.1.2.

- 3.2.2.2.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of a developing area comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.2.2.1.1.2
Shooting operation causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in a developing area (given that such material is present in the area).

AND

- 3.2.2.2.2.1.1.2.1 *
Shooting operation is being performed in the vicinity of a developing area.

    a) This event is identical to event 3.2.2.1.2.1.2.1.1.2.1.

- 3.2.2.2.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the developing area (given that such an operation is being performed in the vicinity).

    a) This event is identical to event 3.2.2.1.2.1.2.1.1.2.2.

- 3.2.2.2.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of a developing area comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.2.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the developing area (given that such material is present in the area).

AND

- 3.2.2.2.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of a developing area.

    a) This event is identical to event 3.2.2.1.2.1.2.1.1.3.1.

- 3.2.2.2.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

    a) This event is identical to event 3.2.2.1.2.1.2.1.1.3.2.

- 3.2.2.2.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of a developing area comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

    a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.2.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the developing area (given that such material is present in the area).

AND

- 3.2.2.2.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of a developing

area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.4.1.

- 3.2.2.2.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.4.2.

- 3.2.2.2.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of a developing area comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.2.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the developing area (given that such material is present in the area).

AND

- 3.2.2.2.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.5.1.

- 3.2.2.2.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.5.2.

- 3.2.2.2.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of a developing area comes in contact with loose coal or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.2.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with loose coal or accumulated coal dust in the developing area (given that such material is present in in the area).

AND

- 3.2.2.2.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.6.1.

- 3.2.2.2.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of a developing area (given that such use or hazard occurs in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.6.2.

- 3.2.2.2.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of a developing area comes in contact with loose coal

or accumulated coal dust in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 3.2.2.2.2.2.1.1
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 3.2.2.2.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operation is being being performed in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.1.1.

- 3.2.2.2.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the developing area causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.2.1.1.2.

- 3.2.2.2.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting, or drilling operations in the vicinity of a developing area to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a.

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.2.2.2.1.1.4 *
Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting, or drilling operations in the vicinity of a developing area reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.2.2.2.1.2
Shooting operation causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 3.2.2.2.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.2.1.

- 3.2.2.2.2.2.1.2.2 *
Shooting operation in the vicinity of a developing area causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.2.1.2.2.

- 3.2.2.2.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by

shooting operations in the vicinity of a developing area to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.2.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of a developing area reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.2.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 3.2.2.2.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.3.1.

- 3.2.2.2.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.2.1.3.2.

- 3.2.2.2.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of a developing area to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.2.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of a developing area reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.2.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 3.2.2.2.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.4.1.

- 3.2.2.2.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.2.1.4.2.

- 3.2.2.2.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of a developing area to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.2.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of a developing area reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.2.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 3.2.2.2.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.5.1.

- 3.2.2.2.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.2.1.5.2.

- 3.2.2.2.2.2.1.5.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of mechanical equipment in the vicinity of a developing area to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.2.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.2.2.2.1.5.4 *
Enough heat energy (without sparks or flame) caused by operation of mechanical equipment in a developing area reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.2.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in a developing area where loose coal or accumulated coal dust exists (given that such material is present in the area).

AND

- 3.2.2.2.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the developing area.

  a) This event is identical to event 3.2.2.1.2.1.2.1.1.6.1.

- 3.2.2.2.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of a developing area causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

  a) This event is identical to event 3.2.2.1.2.1.2.2.1.6.2.

- 3.2.2.2.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of a developing area to raise loose coal or accumulated coal dust to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.2.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.2.2.2.1.6.4 *
Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of a developing area reaches a point in that area where loose coal or accumulated coal dust exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 3.2.2.3
An imported flammable material in a developing area is raised to its ignition point (given that the level of oxygen in the area is sufficient for combustion and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.3.1 *
Presence of an imported flammable material in structures, in equipment, or lying loose at a developing area.

  a) See comments 1.1.2.2.3.1.a, b & c.

- 3.2.2.3.2 ->
An imported flammable material in a developing area is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

> 3.2.2.3.2
An imported flammable material in a developing area is raised to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 3.2.2.3.2.1 ->

A spark or open flame raises an imported flammable material in the developing area to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.3.2.2 ->
  Heat (without flame or spark) raises an imported flammable material in a developing area to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.3.2.3 *
  Spontaneous combustion of an imported flammable material in a developing area (given that the level of oxygen in the area is sufficient for combustion, that such material is present in the area and that there is no ongoing fire anywhere in the mine).

    a) See comment 1.1.2.2.2.2.3.a.

> 3.2.2.3.2.1
> A spark or open flame raises an imported flammable material in the developing area to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.3.2.1.1 ->
  A spark or open flame comes in contact with an imported flammable material in a developing area (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.3.2.1.2 *
  An imported flammable material in a developing area is raised to its ignition point by a spark or open flame (given that a spark or open flame has come in contact with such material).

    a) See comment 1.1.2.2.2.2.1.2.a.

    b) See comment 1.1.2.2.3.2.1.2.b.

> 3.2.2.3.2.2
> Heat (without flame or spark) raises an imported flammable material in a developing area to its ignition point (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

AND

- 3.2.2.3.2.2.1 ->
  Heat energy (without spark or flame) reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

- 3.2.2.3.2.2.2 *
  An imported flammable material in a developing area is raised to its ignition point by heat without spark or flame (given that heat energy reaches a point in the area where such material exists).

    a) See comment 1.1.2.2.2.2.2.2.a.

    b) See comment 1.1.2.2.3.2.1.2.b.

> 3.2.2.3.2.1.1
> A spark or open flame comes in contact with an imported flammable material in a developing area (given that this material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 3.2.2.3.2.1.1.1 ->
  Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

- 3.2.2.3.2.1.1.2 ->
  Shooting operation causes a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

- 3.2.2.3.2.1.1.3 ->
  Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

- 3.2.2.3.2.1.1.4 ->
  Operation of combustion equipment produces a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

- 3.2.2.3.2.1.1.5 ->
  Operation of mechanical equipment produces a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

- 3.2.2.3.2.1.1.6 ->
  Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the developing area (given that such material is present in the area).

> 3.2.2.3.2.2.1
Heat energy (without spark or flame) reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area and that there is no ongoing fire anywhere in the mine).

OR

- 3.2.2.3.2.2.1.1 ->
  Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

- 3.2.2.3.2.2.1.2 ->
  Shooting operation causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

- 3.2.2.3.2.2.1.3 ->
  Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

- 3.2.2.3.2.2.1.4 ->
  Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

- 3.2.2.3.2.2.1.5 ->
  Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

- 3.2.2.3.2.2.1.6 ->
  Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

> 3.2.2.3.2.1.1.1
Coal cutting, rock cutting or drilling operation causes a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

AND

- 3.2.2.3.2.1.1.1.1 *
Coal cutting, rock cutting or drilling operation is being performed in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.1.1.

- 3.2.2.3.2.1.1.1.2 *
Coal cutting, rock cutting or drilling operation causes a spark or open flame in the vicinity of a developing area (given that such an operation is being performed in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.1.2.

- 3.2.2.3.2.1.1.1.3 *
Spark or open flame caused by coal cutting, rock cutting or drilling operation in the vicinity of a developing area comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.3.2.1.1.2
Shooting operation causes a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

AND

- 3.2.2.3.2.1.1.2.1 *
Shooting operation is being performed in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.2.1.

- 3.2.2.3.2.1.1.2.2 *
Shooting operation causes a spark or open flame in the vicinity of the developing area (given that such an operation is being performed in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.2.2.

- 3.2.2.3.2.1.1.2.3 *
Spark or open flame caused by shooting operation in the vicinity of a developing area comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.3.2.1.1.3
Operation of electrical equipment causes a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

AND

- 3.2.2.3.2.1.1.3.1 *
Electrical equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.3.1.

- 3.2.2.3.2.1.1.3.2 *
Operation of electrical equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.3.2.

- 3.2.2.3.2.1.1.3.3 *
Spark or open flame caused by operation of electrical equipment in the vicinity of a developing area comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.3.2.1.1.4
Operation of combustion equipment causes a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

AND

- 3.2.2.3.2.1.1.4.1 *
Combustion equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.4.1.

- 3.2.2.3.2.1.1.4.2 *
Operation of combustion equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.4.2.

- 3.2.2.3.2.1.1.4.3 *
Spark or open flame caused by operation of combustion equipment in the vicinity of a developing area comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.3.2.1.1.5
Operation of mechanical equipment causes a spark or open flame which comes in contact with an imported flammable material in a developing area (given that such material is present in the area).

AND

- 3.2.2.3.2.1.1.5.1 *
Mechanical equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.5.1.

- 3.2.2.3.2.1.1.5.2 *
Operation of mechanical equipment causes a spark or open flame in the vicinity of a developing area (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.1.1.5.2.

- 3.2.2.3.2.1.1.5.3 *
Spark or open flame caused by operation of mechanical equipment in the vicinity of a developing area comes in contact with an imported flammable material in the area (given that such material is present in

the area and that a spark or open flame has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

> 3.2.2.3.2.1.1.6
Use of contraband or other fire hazard causes a spark or open flame which comes in contact with an imported flammable material in the developing area (given that such material is present in the area).

AND

- 3.2.2.3.2.1.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the developing area.

  a) This event is identical to event 3.2.2.1.2.1.2.1.1.6.1.

- 3.2.2.3.2.1.1.6.2 *
Use of contraband or other fire hazard causes a spark or open flame in the vicinity of a developing area (given that such use or hazard occurs in the vicinity).

  a) This event is identical to event 3.2.2.1.2.1.2.1.1.6.2.

- 3.2.2.3.2.1.1.6.3 *
Spark or open flame caused by use of contraband or other fire hazard in the vicinity of a developing area comes in contact with an imported flammable material in the area (given that such material is present in the area and that a spark or open flame has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.1.1.1.3.a.

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 3.2.2.3.2.2.1.1
Coal cutting, rock cutting or drilling operation causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

AND

- 3.2.2.3.2.2.1.1.1 *
Coal cutting, rock cutting or drilling operation is being being performed in the vicinity of a developing area.

  a) This event is identical to event 3.2.2.1.2.1.2.1.1.1.1.

- 3.2.2.3.2.2.1.1.2 *
Coal cutting, rock cutting or drilling operation in the vicinity of the developing area causes heat energy to be produced (given that such an operation is being performed in the vicinity).

  a) This event is identical to event 3.2.2.1.2.1.2.2.1.1.2.

- 3.2.2.3.2.2.1.1.3 *
Enough excess heat energy (without sparks or flame) is caused by coal cutting, rock cutting or drilling operations in the vicinity of a developing areato raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

  a) See comment 1.1.2.2.3.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.3.2.2.1.1.4 *
Enough heat energy (without sparks or flame) caused by coal cutting, rock cutting or drilling operations in the vicinity of a developing area reaches a point in that area where imported flammable material

exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.3.2.2.1.2
Shooting operation causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

AND

- 3.2.2.3.2.2.1.2.1 *
Shooting operation is being performed in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.2.1.

- 3.2.2.3.2.2.1.2.2 *
Shooting operation in the vicinity of a developing area causes heat energy to be produced (given that such an operation is being performed in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.2.1.2.2.

- 3.2.2.3.2.2.1.2.3 *
Enough excess heat energy (without sparks or flame) is caused by shooting operations in the vicinity of a developing area to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.3.2.2.1.2.4 *
Enough heat energy (without sparks or flame) caused by shooting operations in the vicinity of a developing area reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such operations in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.3.2.2.1.3
Operation of electrical equipment causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

AND

- 3.2.2.3.2.2.1.3.1 *
Electrical equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.3.1.

- 3.2.2.3.2.2.1.3.2 *
Operation of electrical equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.2.1.3.2.

- 3.2.2.3.2.2.1.3.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of electrical equipment in the vicinity of a developing area to raise an imported flammable material to its ignition point (given

that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.3.2.2.1.3.4 *
Enough heat energy (without sparks or flame) caused by operation of electrical equipment in the vicinity of a developing area reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.3.2.2.1.4
Operation of combustion equipment causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

AND

- 3.2.2.3.2.2.1.4.1 *
Combustion equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.4.1.

- 3.2.2.3.2.2.1.4.2 *
Operation of combustion equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

a) This event is identical to event 3.2.2.1.2.1.2.2.1.4.2.

- 3.2.2.3.2.2.1.4.3 *
Enough excess heat energy (without sparks or flame) is caused by operation of combustion equipment in the vicinity of a developing area to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.3.2.2.1.1.3.a

b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.3.2.2.1.4.4 *
Enough heat energy (without sparks or flame) caused by operation of combustion equipment in the vicinity of a developing area reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

> 3.2.2.3.2.2.1.5
Operation of mechanical equipment causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

AND

- 3.2.2.3.2.2.1.5.1 *
Mechanical equipment is operating in the vicinity of a developing area.

a) This event is identical to event 3.2.2.1.2.1.2.1.1.5.1.

- 3.2.2.3.2.2.1.5.2 *
Operation of mechanical equipment in the vicinity of a developing area causes heat energy to be produced (given that such equipment is operating in the vicinity).

  a) This event is identical to event 3.2.2.1.2.1.2.2.1.5.2.

- 3.2.2.3.2.2.1.5.3 *
Heat energy (without spark or flame) caused by operation of mechanical equipment reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area and that heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.3.a

> 3.2.2.3.2.2.1.6
Use of contraband or other fire hazard causes heat energy (without spark or flame) which reaches a point in a developing area where an imported flammable material exists (given that such material is present in the area).

AND

- 3.2.2.3.2.2.1.6.1 *
Use of contraband or other fire hazard occurs in the vicinity of the developing area.

  a) This event is identical to event 3.2.2.1.2.1.2.1.1.6.1.

- 3.2.2.3.2.2.1.6.2 *
Use of contraband or other fire hazard in the vicinity of a developing area causes heat energy to be produced (given that such use or hazard occurs in the vicinity).

  a) This event is identical to event 3.2.2.1.2.1.2.2.1.6.2.

- 3.2.2.3.2.2.1.6.3 *
Enough excess heat energy (without sparks or flame) is caused by use of contraband or other fire hazard in the vicinity of a developing area to raise an imported flammable material to its ignition point (given that some excess heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.3.2.2.1.1.3.a

  b) See comment 1.1.2.2.1.2.1.2.2.1.1.3.b

- 3.2.2.3.2.2.1.6.4 *
Enough heat energy (without sparks or flame) caused by use of contraband or other fire hazard in the vicinity of a developing area reaches a point in that area where imported flammable material exists to raise the material to its ignition point (given that such material is present in the area and that enough heat energy has been produced by such means in the vicinity).

  a) See comment 1.1.2.2.1.2.1.2.2.1.1.4.a

  b) See comment 1.1.2.2.1.2.1.2.1.1.6.3.b.

> 4
Initiation of fire in an abandoned area (given that there is no ongoing fire anywhere in the mine).

OR

- 4.1 ->
Initiation of fire by spontaneous combustion of coal and/or other materials in an abandoned area (given that there is no ongoing fire anywhere in the mine).

- 4.2 ->
Ignition of combustible material in an abandoned area of a working panel (given that there is no ongoing fire anywhere in the mine).

> 4.1
Initiation of fire by spontaneous combustion of coal and/or other materials in an abandoned area (given that there is no ongoing fire anywhere in the mine).

AND

- 4.1.1 *
Presence of coal or other materials prone to spontaneous combustion in an abandoned area.

  a) See comment 1.1.1.1.a

  b) Abandoned areas in a coal mine might include mined out panels, unused main roads, mined out sections, or passageways to other mines. These areas fall into several categories:
     i) Accessible abandoned areas, while they might not normally be travelled, still can be, and are sometimes ventilated to provide extra air supply to the mine; such areas would be better considered as main mine areas (see branch 2) where the traffic level is extremely low or zero.
     ii) Inaccessible, but unsealed, areas which are blocked off from human traffic but which are still open to the mine air supply (in some cases these areas areas might be used as air shafts but usually the air-flow is neutral); these areas can have spontaneous combustion problems due to the presence of oxygen, the presence of loose coal, coal fines, and refuse, the lack of ventilation pressure to control heat build-up and methane accumulations, and the lack of regular inspection by mine personnel.
     iii) Sealed areas should be relatively free of hazards because of the absence of traffic and the lack of oxygen; the main consideration here would be that the seals might be imperfect and allow sufficient oxygen for spontaneous combustion as described above to occur.

- 4.1.2 *
Sufficiently high temperatures are maintained for long enough in the abandoned area that would produce spontaneous combustion if no heat were dissipated by air flow (given the type of coal and other materials in the area, and that there is no ongoing fire anywhere in the mine).

  a) See comment 1.1.1.2.a.

- 4.1.3 *
There is an air-flow through the abandoned area permitting enough oxygen in contact with the coal and other materials to allow spontaneous combustion (given that there is no ongoing fire anywhere in the mine).

a) As described in comment 4.1.1.b, this can occur if the area is unsealed or if the seals are imperfect.

- 4.1.4 *
The flow of air through the abandoned area does not dissipate enough heat to prevent spontaneous combustion (given that the temperature maintained in the area is high enough in the absence of such dissipation to produce such a spontaneous combustion, that there is enough air-flow in the area to provide the required oxygen and that there is no ongoing fire anywhere in the mine).

a) See comment 1.1.1.4.a.

-------

> 4.2 *
Ignition of a combustible material in an abandoned area of a working panel (given that there is no ongoing fire anywhere in the mine).

a) Because the low traffic and absence of equipment in such an area, there is little possibility of an ignition by other than spontaneous combustion.

APPENDIX 1

DSS File No.: 07SQ.23440-5-9009

NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES

REQUIREMENT

On behalf of the Department of Energy, Mines and Resources to complete by December 30, 1985, a review into available materials, methods and techniques that could be used effectively and beneficially in the place of wood as a support and construction material within Cape Breton coal mines. A particular emphasis must be placed in the review on the possibilities of using materials that can be obtained from sources within Cape Breton and the Maritime provinces.

BACKGROUND

Timber and lumber were the first support materials to be used within mines. The use of wood was not originally considered to be a hazard in the mining environment as the industry was labour intensive and the tasks were mostly accomplished by persons using hand tools. Machines and machinery were not greatly in evidence and the early power source for the use of machinery within coal mines was mainly compressed air. Progressikve advance in mining technology has seen the introduction over the last quarter of a century of sophisticated and complex electrical, mechanical, and hydraulic plant and machinery into the coal mining environment.

Such plant and machinery has raised the potential sources for ignitions from a few to many. Mine fires that have assumed disastrous proportions and have caused in some cases serious loss of life, can be attributed to the spread of fire throughout major sections of such mines. The agent for propogation of extensive fire zones has been an abundant presence of wood for either the purpose of support covering or construction. The closure of No. 26 mine of the Cape Breton Development Corporation was the result of such a fire zone.

Endeavours have been made in many countries to counter the potential for serious fires in underground coal mines. The U.K. National Coal Board has opted for the fire retardant treatment of timber. This scheme, though costly, has had only partial success in the prevention of the propogation of fires.

The W. German mining industry has made considerable progress with an over all reduction in the usage of wood by 92% during the last two decades. This has been spurred by two considerations, the need for economy, and the demands of safety. The need for economy has been dictated by the depletion of indigenous resources of wood, and the need for safety is dictated by the working of coalfields that have high liabilities to spontaneous combustion and a serious history of fires.

There are places in a mine where the risks associated with the use of wood are small and the benefits are great. Such places should not be denied the benefits of the use of wood.

STATEMENT OF WORK

PHASE I

1. To develop a rational framework such as the U.S. Bureau of Standards Fault Tree Analysis System from which an assessment will be made of the relative fire risks that are encountered in various parts and places of the undersea workings of coal mines that are operated by Cape Breton Development Corporation. The assessment must take into account as a minimum the following:

STATEMENT OF WORK (Cont'd.)

i) The numbers and frequency of persons working in and passing through such placed.

ii) The type of machinery, plant, and equipment in such places.

iii) The possible ignition sources/mechanisms.

iv) The materials and methods of construction that are applicable, and the support of the roof, sides, and if necessary the floor appropriate to such places.

v) Open or concealed fires.

vi) Ease of personnel evacuation and direct fire fighting.

vii) Ease of early detection by remote and/or on-site means.

viii) Risk of methane/coal dust accumulations.

ix) Anticipated rates of propogation/development of open or concealed fires.

2. To review non-combustible alternatives and substitutes to the use of wood in such places. The review must address an order in the use of such substitutes and alternatives from those places with the highest risk to those with the lowest.

PHASE II

1. To examine the potential for the use of local materials and resources of Cape Breton and the Maritime Provinces for the production of substitutes and alternatives to wood.

2. To estimate the comparative operating, material, and if appropriate repair costs of the substitutes and alternatives in their fields of application.

3. To identify any health and safety risks associated with the above described alternatives and substitutes and prescribe suitable safeguards.

Volume

2

NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES

VOLUME 2

DSS FILE NUMBER: 07SQ.23440-5-9009

303pp

NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES

VOLUME 2

By

JACQUES, WHITFORD AND ASSOCIATES LIMITED

With

P. LANE AND ASSOCIATES LIMITED

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EXECUTIVE SUMMARY

This report, prepared for Energy, Mines and Resoures by Jacques, Whitford and Associates Limited reviews and presents non-combustible replacement materials, methods, and techniques to reduce the usage of wood in coal mines and assesses the fire risk. The document represents the culmination of several months of literature searches, data compilations, and computer modeling.

The use of wood in the coal mines represents a significant fire hazard because of the large fuel load it presents as well as the continous flame path it creates through extensive areas of the mine. The risk of fire in the CBDC coal mines would be greatly reduced if the use of wood could be minimized. Longwall mining methods were the focus of this study as it is considered the "worse case" situation for wood usage.

The first phase of the study developed a fire risk assessment of the extensive volume of wood used in the coal mines. A large fault tree model, a deductive methodology based upon Boolean algebra, was constructed for a longwall mine. It begins with the definition of an undesirable top event, a mine fire, and proceeds to diagram all important causal pathways of events leading to the fire. The qualitative model was developed around four major areas of the mine: working panel, main entry tunnel, developing area, and abandoned area. Combustible materials were considered to be of three types: mixtures of methane gas and airborne coal dust, loose coal and accumulated coal fines, and imported flamable materials such as fuels, explosives, cloth, plastic, paper, and wood.

Although analysis of the model is limited without quantitative data, preliminary reviews indicated that wood was a potentially significant contributor to approximately one third of 857 file causal pathways of the model. It was

concluded from this work that fault tree analysis can be successfully applied to mine fire risk assessemnt and that the model should be developed to produce a quantitative risk analysis.

The second phase of the study reviewed technologies for wood replacement in underground coal mines and evaluated the use of indigenous materials for these roles.

The current applications of wood in CBDC coal mines were identified, including construction materials, gateside packs, roadway lagging, cavity stabilization, remedial support, rail ties, and face-line development. Alternate materials and technologies which could be used to replace these uses of wood such as stowing methods and fly ash cements were also reviewed.

The priority for wood replacement was established employing a predictive fire risk index founded upon the fault tree risk assessment developed in Phase I. The wood replacement priority, in descending order of importance is as follows: lagging, wooden packs, cavity filling materials, construction material, rail ties, and remedial support members.

Fly ash and anhydrite, both readily available in Cape Breton, were identified for use in gateside packs, cavity fillings, and construction materials. Other recommendations included coating standing timber with a mine sealant, replacing wood lagging with welded wire mesh panels, and using shotcrete or gunite as a roadway lining.

Résumé des recommendations

Cet étude a été préparé par la compagnie Jacques, Whitford & Associates Limited pour le Ministère de l'Énergie, mines et ressources Canada. On a fait l'étude des matériaux incombustibles étant capables de remplacer le bois, les méthodes et les techniques servant à réduire l'usage du bois dans les houillères, ainsi que l'évaluation du risque d'incendie. L'étude rassemble tous les données, la recherche de la documentation, et le computer modeling obtenus pendant plusieurs mois.

Dans l'industrie houillère, le bois devient un grand risque d'incendie à cause de sa capacité en tant que combustible et quand le bois crée un trajet de feu qui traverse le réseau souterrain de la mine. Donc, le risque d'incendie dans les houillères de la Société de développement du Cap-Breton serait réduit considérablement en minimisant l'usage du bois. Étant donné que la méthode d'exploitation minière de front de taille (longwall mining method) est considérée comme une des méthodes les plus problématiques pour l'usage du bois, ce rapport a seulement fait l'étude de cette méthode.

Eu premier lieu on a évalué le risque d'incendie dans les houillères d'après l'étendue de bois utilisé. Par la suite, on a rédigé un modèle «fault tree», une méthodologie déductive basée sur l'algèbre Boolean, proprice à l'exploitation minière de front de taille. Le modèle établit, d'après la définition de l'événement initial tel qu'un feu à l'intérieur de la mine, un schéma de toutes les étapes qui conduisent au feu.

Le modèle a été développé avec l'aide des quatres endroits principales de la mine: le front de taille, l'entrée de galerie principale à flanc de coteau, le district minier en voie de développement, ainsi que le district minier abandonné. Les matières combustibles classées d'après trois types comprenaient: un mélange de méthane et de poussier aéroporté; le charbon et les accumulations de particules fines de charbon; ainsi que les matières inflammables provenants de l'extérieur telles que les carburants, les explosifs, le linge, le plastique, le papier et le bois.

Malgré une analyse quantitative limitée à cause d'un manque de données, l'étude préliminaire a démontré que le bois contribuait à approximativement un tiers des 857 causal pathways importantes du modèle.

On a donc pu conclure d'après ce travail que le modèle fault tree peut être employé avec succès à l'évaluation du risque d'incendie à l'intérieur d'une mine, et pourrait même être développé pour comprendre une analyse quantitative de ce risque d'incendie.

La deuxième étape de l'étude mena une analyse des technologies visant à remplacer le bois dans les houillères souterraines tout en comprenant le rôle des matières autochtones dansce domaine.

L'usage actuel du bois dans les mines de charbon appartenant à la Société de développement du Cap-Breton en somme comprend le bois comme matériel de construction, comme remblais de voie de roulage, garnissages de route, stabilizations de cavité, soutènements traverses, dans le développement de tailles chassantes. De plus, le bois pourrait être employé dans les méthodes de remblayage et en tant que ciment fly ash.

Tou ces usages ont été étudiés dans ce rapport.

On a également obtenu un indice à risque d'incendie fondé sur l'évaluation du risque développé d'après le modèle fault tree durant la première étape. Cet indice a pour suite établit les priorités dans le remplacement du bois. Les priorités en ordre d'importance sont comme suit: le garnissage, les remblais, les matériaux pour remblissage de cavité, les matériaux de construction, les traverses et le soutènement correctif.

Le fly ash et l'anhydrite sont abondants au Cap-Breton et l'étude les a considérés pour leur usage en tant que remblais de voie de roulage, dans le remblissage de cavité, et comme matériel de construction. On recommende également leur emploi dans l'ignifuge du bois, dans le remplacement du garnissage par les panneaux de grillage, et en utilisant le shotcrete ou le gunite comme matériaux de revêtement routier.

PREAMBLE

Background and Project Rationale

The Sydney coalfield is situated in northeastern Nova Scotia, on and offshore Cape Breton Island. It consists of two sectors: a small land area (520 km^2) and a large offshore region. Both areas form a large Carboniferous basin which extends towards Newfoundland, occupying in the order of 36,000 km^2.

The Sydney coalfield contains the largest coal reserve in Eastern Canada, 98 percent of which is submarine as the coal seams dip gently approximately 5° seaward. The coals are ranked as high volatile A bituminous (Hacquebard, 1983) but are medium volatile bituminous in zones.

The Cape Breton Development Corporation (CBDC) operates two collieries in the Sydney coalfield, the Lingan and the Prince on the Harbour and Hub seams, respectively. A third colliery, the new Phalen mine is presently being developed and should commence production in the year 1987. The anticipated output of the Phalen in 1988 will be in the order of 1.4 million tonnes. The Donkin Mine, which is not as yet producing, is not expected to begin operations until the 1990's.

The CBDC currently produces in the order of 2.7 million tonnes of coal annually and employs in excess of 3000 personnel directly (NSDME, 1984).

Large volumes of wood are utilized in underground coal mines in a variety of roles, such as, mine supports, permanent and temporary structures, rail ties, doors. The use of wood is considered to be costly to supply, and manual placement techniques are expensive. Historically, wood presented minimal fire hazards as the mine operations were typically labour intensive, using hand tools and pneumatic equipment which were limited sources of ignition. The quantities of wood presently used in the mines, however, is virtually unchanged even since the introduction of extensive electrical and mechanical equipment has increased the potential for ignition of the wood.

The rapid spread of coal mine fires may be attributed to the use of wood in coal mines and close proximity of the sources of ignition. The Cape Breton collieries have experienced underground fires, of varying degrees of severity; the most recent and disastrous of which resulted in the permanent closure of the No. 26 Colliery and loss of life.

Current research work is being performed to reduce the dependence on wood; thereby reducing the incidence of fire. It is within this context that Jacques, Whitford and Associates Limited were awarded a contract to assess the relative fire risks encountered in the various segments of the CBDC collieries and to review the non-combustible alternatives and substitutes for wood in the mine operation, including potential indigenous sources of replacement materials. The terms of reference for the study were outlined in the statement of work which has been attached as Appendix 1.

Study Participants

The contract was awarded by Supply and Services Canada in May, 1985, under the direction of Mr. G. A. Haslett, P.Eng. of the Cape Breton Coal Mine Research Laboratory (CBCMRL). The prime consultant Jacques, Whitford and Associates Ltd. assigned Mr. John Amirault, M.Eng., P.Eng., as project manager. The key personnel participating in the project were as follows:

- Jacques, Whitford and Associates Ltd. (JWA)
  Mr. D.S. Jones, P.Eng., MBA - Mining Engineer
  Mr. C.G. Sheppard, B. Eng. - Mining Engineer

- P. Lane and Associates (PLA)
  Dr. P. Lane - Senior Systems Analyst
  Mr. J.A. Wright - Systems Analyst

P. Lane and Associates Limited performed the risk assessment of underground fire in Cape Breton coal mines, using deductive fault tree analysis, entailed the construction of a large qualitative fault tree model of four areas in the longwall mine. Computer techniques were utilized for the construction of the model.

Jacques, Whitford and Associates Limited investigated the alternative technology and techniques suitable as a non-combustible wood substitute and also reviewed the sources of raw materials, indigenous to the region, which could be utilized in wood substitutions. This work was undertaken in two parts. The first of which gathered technical information from manufacturers, suppliers, mining companies using the technology, and finally research groups such as CANMET, NCB, MRDE and USBM. Several computer literature searches were performed so as to obtain data on the current trends in industry and research.

Upon the identification of wood alternative techniques applicable to the CBDC coal mines, indigenous sources were sought, which could provide the necessary raw materials for the manufacture of these products. Data was collected through communication with local producers of limestone, gypsum, anhydrite, coal and mineral wastes as well as the Nova Scotia Department of Mines and Energy (NSDME).

Report Organization

The report is presented in two phases.

Volume I contains Phase I - Risk Asessment of Underground
Fire in Cape Breton Coal Mines.

Volume II contains Phase II Part I - Wood Substitute
Investigation, and
Part II - Review of Indigenous
Materials

This preamble accompanies each volume and contains a complete Table of Contents for the entire report.

The document has been structured so that any Phase or Part can be extracted and used in its entirety, separate from the remaining portions of the report.

Phase I is presented in five sections. Details discussed include an introduction to fault tree analysis, a description of the model and a discussion of the results.

Phase II is presented in nine and ten sections for Parts I and II, respectively. Part I discusses the various wood substitute technologies which are available and currently used by the coal mining industry; including gateside packwall supports, cavity filling techniques, and new face development. Part II presents the sources of indigenous materials used in the technologies discussed in Part I and includes mineral aggregates, limestone, gypsum/anhydrite, etc. An evaluation of the cost of these materials is presented. We have also prioritized the areas of wood replacement.

Respectfully submitted,

P. Lane & Assoc. Ltd.

per Patricia A. Lane

Patricia A. Lane, Ph.D.

John A. Wright, B.Sc.

Jacques, Whitford & Assoc. Ltd.

per

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NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES.

PHASE I: RISK ASSESSMENT OF UNDERGROUND FIRE IN CAPE BRETON COAL MINES

By P. LANE AND ASSOCIATES, LTD.

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NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES

PHASE II - PART I

WOOD SUBSTITUTE INVESTIGATION

By

JACQUES, WHITFORD AND ASSOCIATES LIMITED

With

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SUMMARY

The Cape Breton Development Corporation (CBDC) operates two undersea longwall coal mines in the Sydney Coalfield, Cape Breton Island, Nova Scotia. An extensive use of untreated wood in the coal mines represents a significant fire hazard because of the large fuel load it presents as well as the continuous flame path it creates through extensive areas of the mine. The risk of fire in the CBDC coal mines would be greatly reduced if the use of wood could be minimized.

The current applications of wood in the CBDC coal mines are identified and include: construction materials, gateside packs, roadway lagging boards, cavity stabilization work, remedial support members for roadway support structures, rail ties and face-line development work.

The study reviews materials and technologies which can be used to replace wood in each of the above topic areas. These products are either currently employed in international mining practices or are being developed for this application.

Conclusions and recommendations on the most appropriate product(s) for CBDC coal mines are deferred to Part II of this report following a review of locally and regionally available materials.

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1.0 INTRODUCTION

The Cape Breton Development Corporation (CBDC) uses extensive volumes of untreated wood in its undersea coal mine operations in the Sydney Coalfields, Cape Breton Island, Nova Scotia.

The imported flammable material represents a large fuel load in the event of an ignition which could sustain a major underground fire for an extended period of time. Also, several applications of wood create a continuous flame-path through extensive areas of the mine. This flame-path represents a high risk factor for mine personnel and plant, in the event of an ignition, due to the rapid rate of flame spread on the surface of untreated wood.

1.1 Purpose of Study

The purpose of this study is to identify non-combustible materials and alternative technologies that can be used in the CBDC coal mines to replace wood, in its many applications. This review reports only those materials and technologies which have been employed or researched for use in underground mines. No attempt is made to identify new materials and technologies that require extensive R & D efforts prior to implementation. This literature review will constitute Phase II - Part I of this report.

The non-combustible materials and technologies review was conducted concurrently with the development of a descriptive fault tree risk analysis model for the CBDC coal mines. The risk analysis model provides a rational framework to assess the risk of fire associated with the various uses of wood in coal mines. The interaction between project team members during the development of these two studies ensured that thorough and consistent information was maintained on these two diverse subject matters. It also facilitated information sharing between the two technical groups (risk analysis modelling group and mining engineers) that was essential to the successful completion of this work. The fault tree risk analysis model is presented in Phase I of this report.

A review of the potential use of local materials and resources from Cape Breton Island and the Maritime Provinces for the production of substitutes for wood in the CBDC coal mines is reported in Phase II - Part II of this report. All conclusions and recommendations on alternative materials and technologies are conducted therein.

1.2 Scope of Study

The study of non-combustible materials and alternative technologies was preceeded by a review of the current uses of wood at CBDC coal mines to guide the literature review. From this preliminary investigation, it was determined that only one of the existing mining operations, as described below, would be used for this study:

Lingan Colliery - advance longwall operation with in-line ripped gateroads supported at the gob-side by a wooden packwall.
Prince Colliery - retreat longwall operation with single-entry inseam drivage gateroads.

The rational for selecting the Lingan Colliery for this study are as follows:

- the annual wood usage volume is larger at Lingan Colliery versus Prince Colliery due to the difference in mining methods used;

- the Lingan Colliery is an "older" operation than the Prince Colliery and has a larger physical plant which presents more potential locations for ignition and a longer escape route in the event of a fire;

- the wood usages identified at Lingan Colliery includes all the usages at Prince Colliery; however, the reverse statement is not true.

1.3 Literature Search

A variety of techniques were used to source references to the literature on wood replacement materials and technologies.

These methods include the use of two (2) computer based technical search services; IEA Coal Abstracts and MINTEC, both supported by QL Systems Ltd., Kingston, Ontario. Table 1.1 presents the list of searches which were conducted, the number of references cited and those which were useful. As QL Systems does not support the keyword "hit" documentation, it is not possible to include this statistic in Table 1.1. The literature searches were conducted on narrowly defined topics through appropriate keyword combinations to minimize unrelated references being cited. Abstracts were obtained for all references and appropriate texts were sourced following a review of the abstracts.

References to work by the Mining Research and Development Establishment (MRDE) of the National Coal Board (NCB) was obtained by reviewing the Annual Reports of the MRDE from 1976 to the present. Also telephone conversations with NCB personnel were used to discuss specific topics of interest. Texts of pertinent references were obtained from the NCB.

An index to Mining Research Programs conducted by the U.S. Bureau of Mines (USBM), Department of the Interior, between January 1970 - May 1984 was used to generate reference material for U.S. work on the subject matter. Texts of important references were obtained from the National Technical Information Services (NTIS) or directly from the USBM. Telephone conversations were also conducted with USBM personnel on specific topics.

International suppliers and equipment manufacturers were invited by letter or telephone to submit technical information and material/equipment specifications for review. Where possible appropriate documentation has been incorporated into the text, figures or tables of this report.

TABLE 1.1: Computer Based Literature Search
(MNT & IEA Coal Data Bases)

TOPIC*	REFERENCES AND ABSTRACTS	USEFUL TEXTS SOURCED
Fire-Retardants and Coatings	14	10
Lagging Materials	90	37
Gateside Packwalls and Face Backfilling	215	15
Cavity Filling	10	9
Foamed Cements	3	3

* Many discrete combinations of keywords were used to conduct these literature searches.

2.0 WOOD USAGE IN CBDC COAL MINES

The usage of wood in the Cape Breton Development Corporation (CBDC) coal mines has been identified in the following applications:

- advance longwall gateroad packs;
- lagging behind steel arch supports;
- cavity stabilization;
- remedial support member at roadway intersections;
- construction material;
- railroad ties for rail haulage/transportation system;
- temporary support member while establishing a new face and stripping a completed face.

The consumption rate of wood in 1984 at Lingan Colliery for gateside packs and lagging was identified (Kochhar, 1985) as:

Application*	Size	Type	Pieces
Gateside	152.0 x 15.2 x 6.4 cm	Hardwood	300,000
Packs	152.0 x 15.2 x 12.7 cm	Hardwood	116,500
Lagging	152.0 x 10.2 x 15.2 cm	Softwood	112,000

* The other identified wood usages are small volume in comparison and no statistics were available for reporting.

There is no fire-retardant treatment of any wood used at CBDC coal mines.

In several of the applications identified above, alternative technologies to wood are either under investigation or are currently used in conjunction with wood.. A description of wood application follows; however, for completeness of this report, the current work being done at CBDC Coal Mines on alternative technologies to wood will be discussed.

2.1 Advance Longwall Gateroad Packs

The advance longwall extraction method, employed at Lingan Colliery, necessitates the provision of gateside packs to reduce gateroad convergence to acceptable levels. The gateroads are maintained in line with the face and are developed by ripping an arch profile in the sandstone/shale roof.

Two-piece rigid rolled steel joist (RSJ) splayed leg arches (4.17 m x 3.05 m) are used in conjunction with wood lagging as the standard gateroad support, Figure 2.1. The tailgate (exhaust) is developed by a shot- fired, half-heading ripping behind the face. The maingate (intake) is developed by in-line ripping with a DOSCO Roadheader Cutting and Loading (DRCL) machine. The wooden packs which are constructed on the gob side of the tailgate and maingate comprise (1.52 m x 1.52 m) and (0.76 m x 0.76 m) wooden chocks separated by a 0.46 m wide gap which is packed with stone dust bags. The (1.52 m x 1.52 m) chock is a 60% solid hardwood structure while the (0.76 m x 0.76 m) chock is 50%. The 60% chock is constructed to have a solid hardwood face at the gateroad. A diagram of the conventional packwall constructions used at Lingan Colliery is given in Figure 2.1

At Lingan Colliery, the materials supply program of wood for pack construction in the tailgate creates a large inventory of wood. This inventory often extends for 50 metres along the gateroad. The loose, irregular storage of this material, as evidenced in Photograph 1, constitutes a large fuel load in the event of a fire.

The current work being done by CBDC on new gateroad support systems include:

- a modified wooden pack design;
- pneumatic stowing of the ripping debris in the pack;
- monolithic pump pack systems.

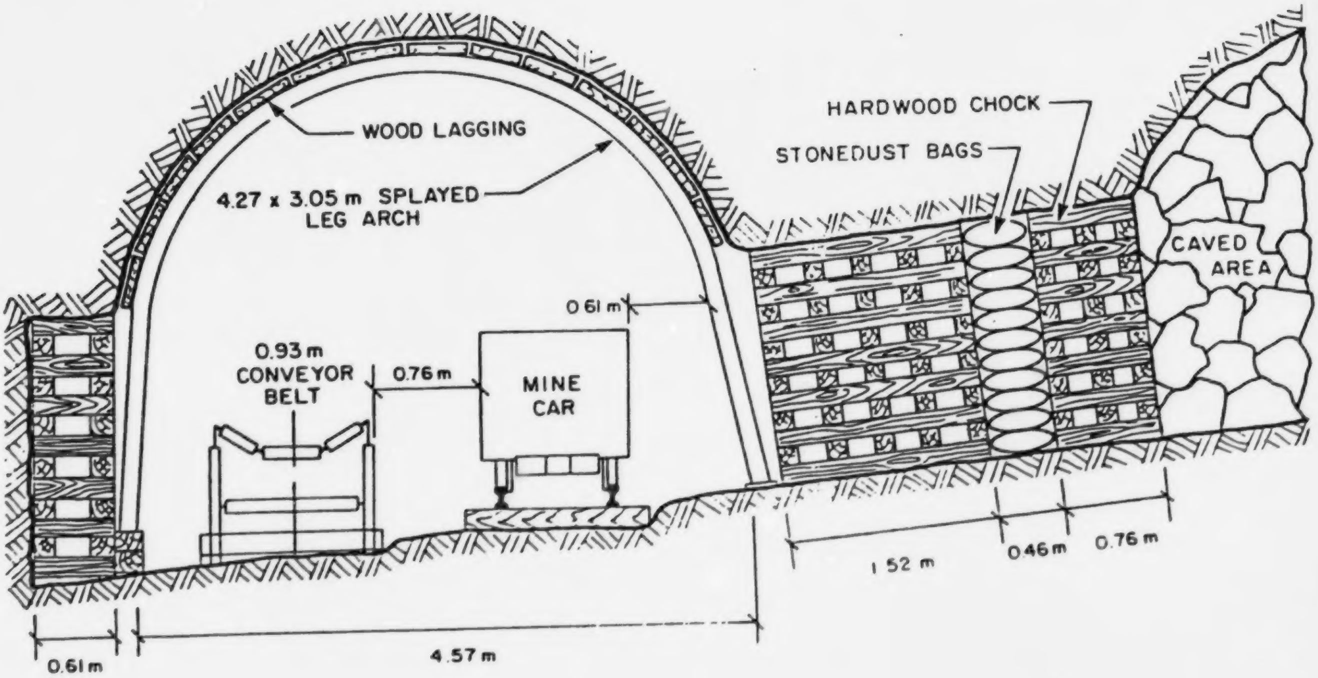
HARDWOOD CHOCK
STONEDUST BAGS
WOOD LAGGING
4.27 x 3.05 m SPLAYED LEG ARCH
CAVED AREA
0.61 m
0.93 m CONVEYOR BELT
0.76 m
MINE CAR
1.52 m
0.46 m
0.76 m
0.61 m
4.57 m

Figure 2.1 Conventional Maingate Packwall Construction used at Lingan Colliery (1984) (AMC, 1984)

A new (1985) design of wooden packwall is being evaluated on the 6 West Wall at Lingan Colliery in both gateroads. This design includes a 100% wooden chock (2 m x 2 m) at the gateside and a 50% wooden chock (0.8 m x 0.8 m) at the gob-edge. A brattice cloth is hung between the double packs to minimize ventilation air leakage. This design is shown in Photograph 2.

In 1983, CBDC experimented with a DRCL unit feeding a pneumatic stowing machine to stow the ripping debris in the pack area of a tailgate roadway. This trial was abandoned after a short period due to the excessive dust created by the stowing machine.

Recent work, (1983 to current), has been done on the introduction of monolithic pump pack systems at Lingan Colliery. Trials have been conducted using the Aquapak and the Astrapak Systems. These systems require the importation of premixed, bagged cement materials from the United Kingdom. CBDC in conjunction with the Cape Breton Coal Research Laboratory (CBCRL) CANMET are currently investigating a use of the Flashpack System, utilizing a flyash by-product from the Nova Scotia Power Corporation, Lingan Power Generating Plant.

2.2 Wood Lagging

Lagging products used at the CBDC Coal Mines include wood, Photograph 3, and corrugated steel sheets, Photograph 4. The corrugated steel has been used largely in main roadways while the longwall gateroads are lined with wooden lagging boards. Wood is also used to backfill the area between the lagging and the extracted roadway profile, Photographs 4 and 5.

The high volume usage of wood as a lagging and backfilling material constitutes an extensive fuel load as well as providing a continuous flame path throughout much of the mine.

A current trial using wire mesh panels with single hooks (therefore engage only one arch) as a lagging material is being evaluated. As can be observed in Photograph 6, wood is still used to provide a backfilling function between the steel arch and the roadway profile.

2.3 Cavity Stabilization

The occurence of cavities in the roof structure of the production face, gateroads or mainroads of CBDC coal mines necessitate a laborious and dangerous rehabilitation process using open wooden chocks. Depending on the extent of the cavity, a considerable volume of wood can be used in this remedial strata work, Figure 2.2. A second factor which increases the potential fire hazard of a wood packed cavity is that methane will migrate to a non-ventilated cavity and may create a potentially explosive atmosphere (between 5 percent - 15 percent methane concentration in the air) surrounding the wood. The concentration of methane is likely to be highest in the tailgate and face area and lowest in the maingate. Consequently, it is possible to rank the potential fire hazard created by the wood used in cavity stabilization work based on the location of the cavity as well as the quantity of wood used.

2.4 Wood Chock Support for Roadway Intersections

Roadway intersections are zones of high stress which require heavy support structures to maintain the integrity of the opening. The practice at CBDC Coal Mines is to use two designs for intersection support. Perpendicular roadway intersection supports are based on post and beam structural members using carrier beams and joist members as shown in Photograph 7. Curved roadway intersection supports comprise rigid RSJ arch supports plus beam members at the abutment of the junction and a carrier beam along the straight roadway, Photograph 8.

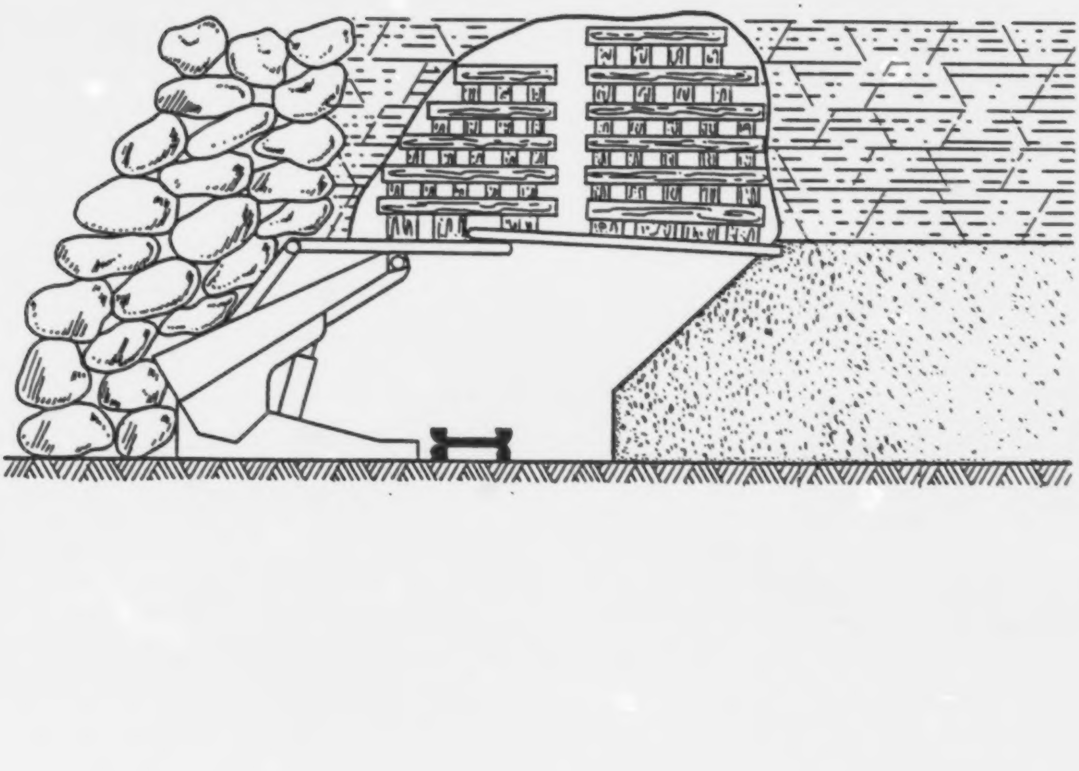

Figure 2.2 Cavity Stabilization of the Face Using Open Wooden Chocks (Dalzell, 1985)

Remedial work using wooden chocks is often required for the steel supports at roadway intersections. Though the steel supports for the perpendicular intersections appear to need only limited remedial work, Photograph 7; the curved intersection requires extensive chock structures to underpin the steel support system, Photograph 9.

The curved roadway intersection is used to transport material from the maingate into the gateroad by a rail haulage system. The switch and the curved track in this area increase the risk of derailment and consequently the chance of frictional ignition. The use of wooden chocks to underpin the steel supports increases the fuel load in the area, and thus, creates a potentially dangerous situation.

2.5 Construction Material

Construction with wood in the CBDC Coal Mines constitutes a relatively low volume usage; however, some applications are better served by non-flammable materials to reduce the potential risk due to fire. The uses of wood as a construction material have been identified as follows:

- underground mechanical and electrical room construction;
- construction of operator enclosures over the main belt line, Photograph 10;
- construction of ventilation and fire doors, Photograph 11, and Photograph 12;
- wooden blocking to support mechanical, electrical equipment and pipelines, Photograph 9;
- miscellaneous, small construction such as benches in areas where mine personnel wait for transportation to surface, Photograph 13.

Normal weight concrete block with mortared joints are currently used in the construction of some mechanical electrical rooms, Photograph 14, as well as in the construction of stoppings, Photograph 15.

2.6 Rail Ties

The endless rail haulage system used in the main roadways, the rope haulage rail system used in the tailgate, and the diesel operated rail system used in the maingate, require the use of a large volume of wooden rail ties, Photograph 16.

During operation, sufficient dirt and coal is spilled on these rail ties that they are buried and therefore not exposed to the atmosphere. However, in the event of a railcar derailment, these ties would likely be exposed and become part of the fuel load in the event of an ignition.

Work is currently being conducted on the use of a formed metal tie to replace the wooden ties.

2.7 New Face Line Development

The development of a new face line at CBDC Coal Mines requires the drivage of a single entry opening the length of a new production face. This area is temporarily supported by a variety of wooden structures such as chocks, props and slabbed bars until the powered supports are set. This wood is allowed to cave into the gob on the advance of the face and therefore does not constitute a long term fire hazard.

Similarily, when a wall is completed, wooden posts and beams are used for temporary support while "stripping" the wall.

PHOTOGRAPH DESCRIPTIONS

1. Storage of timber for gateside packwall construction in the tailgate. Timber piled along approximately a 50 meter length of the gateroad in a loose, irregular manner.

2. New packwall design on trial. Gateside chock is 100 percent, (2 m X 2 m) hardwood. The gob edge chock is 50%, (0.8 m x 0.8 m) hardwood. Brattice cloth is hung between the two chocks to minimize ventilation air leakage through the gob area. (Note: Gateroad on left and gob on right side of photograph).

3. Wooden lagging behind steel arch supports. Roadway convergence can be observed by the deformation in several arch structures.

4. Corrugated steel sheet lagging used to line the main roadways and limited sections of gateroads. Wood is used as a backfill material behind the corrugated steel sheets.

5. Extensive use of wood to backfill behind steel arch supports. This volume of wood was required to fill a large void created by a significant area change in the roadway profile. The area shown is the intersection of the main roadway with a large galley used to facilitate an underground coal storage bunker at Lingan Colliery.

6. Wire mesh panels with single-hooked end to engage one arch flange are on trial as a back-lagging material at Lingan Colliery (November, 1985). The continued use of wood as a lagging and backfill material behind the wire mesh panels is to be noted.

7. Perpendicular roadway intersection showing support system. Steel I-section carrier beams are supported at the corners on wooden chocks. Steel I-section joist members are supported by the carrier beam with lagging timber wedged between the webs of adjoining joists.

8. Curved roadway intersection showing the design of the steel arch support system. Steel joist members are used at the inside corner of the support system to span the abutment area of the intersection. A heavy I-section carrier beam is U-bolted to the arch supports in the main roadway to stiffen the support structure.

9. Extensive use of wooden chocks as a remedial support member to underpin badly deformed steel support structure at a curved roadway intersection. The close proximity of the rail haulage tracks and the rail switch to the wood chocks is to be noted.

10. Wooden structure, to serve as the conveyor belt operator enclosure, constructed over the belt line.

11. Plywood ventilation doors to provide access through an airlock in a main roadway. The large doors are to accomodate travel of the endless rope haulage system, and the small doors for passage of personnel.

12. Plywood ventilation door installed in a gateroad.

13. Minor wood construction - benches used while waiting for transportation to surface.

14. Mechanical and electrical rooms constructed of normal weight concrete block with mortared joints.

15. Ventilation stopping constructed of normal weight concrete block with mortared joints.

16. Wooden rail ties used to secure all rail haulage systems in main roadways and gateroads.

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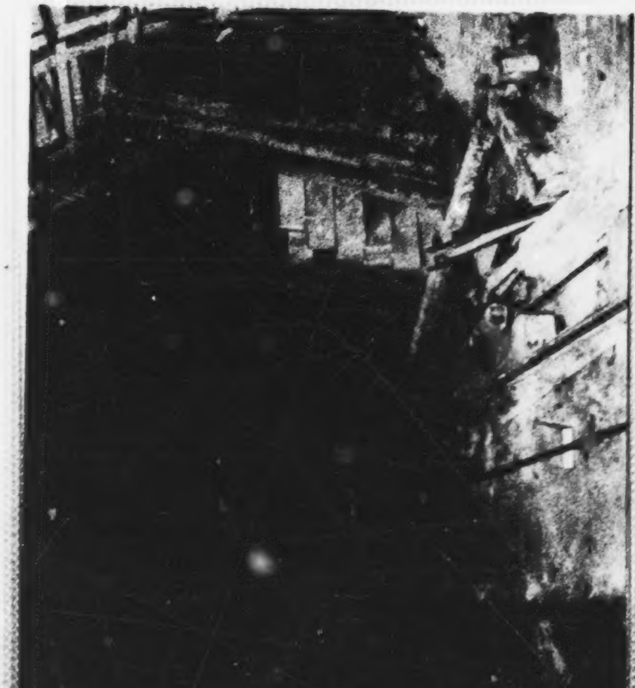

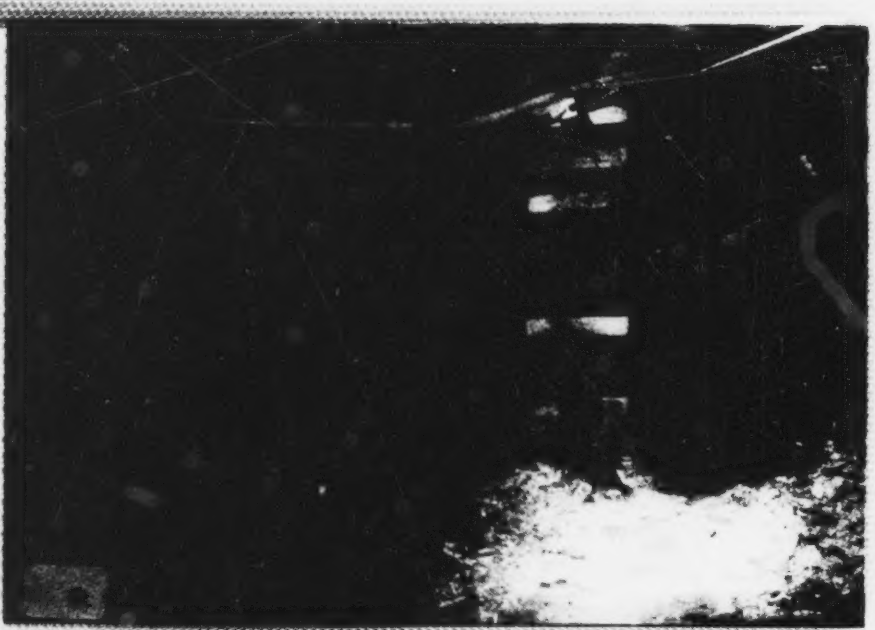

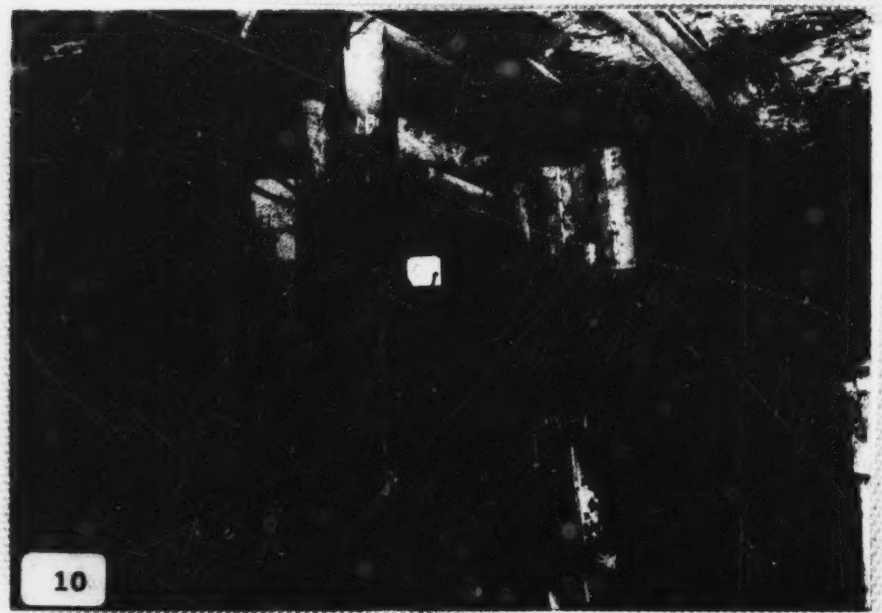

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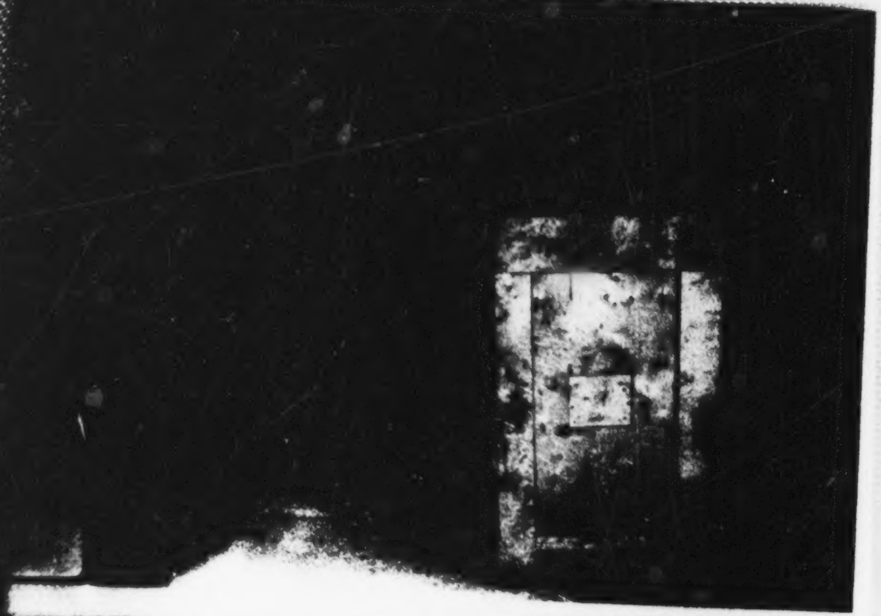

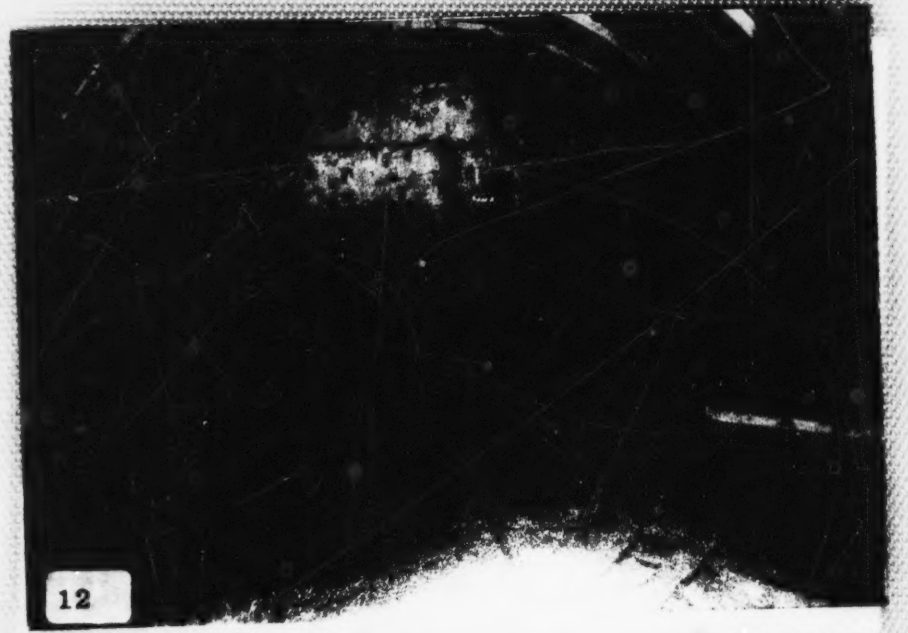

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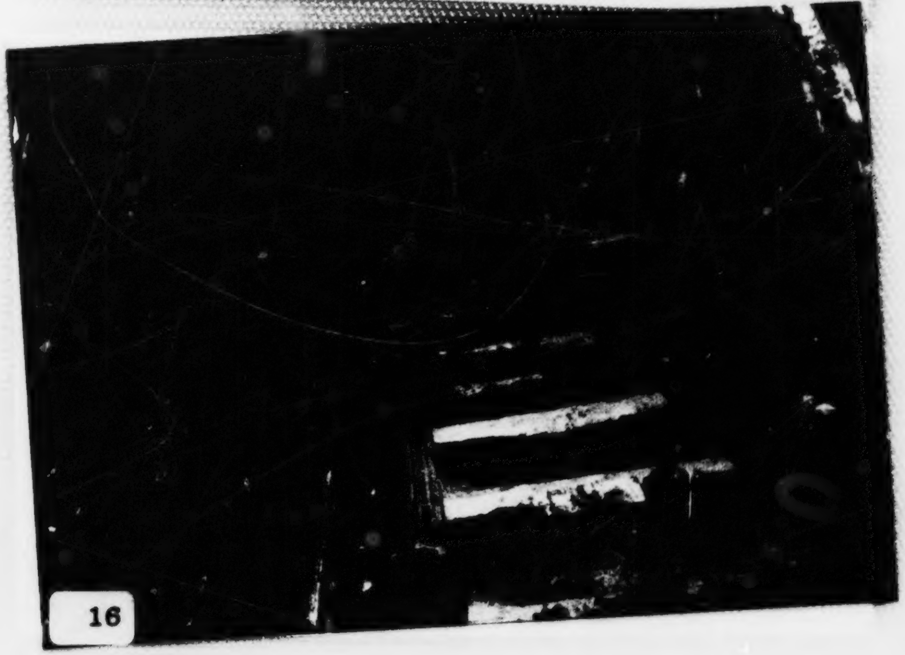

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3.0 FIRE RETARDANT TREATMENT OF MINE TIMBER

Wood consists essentially of lignin and cellulose. If wood is heated, it will decompose in a sequence of temperature dependent reactions collectively known as pyrolysis. The range of reaction initiation temperatures in the pyrolysis of wood is from 100°C to 500°C. The reactions which occur below 280°C are endothermic and pose only a limited problem within a mine while those which occur at temperatures greater than 280°C are exothermic (sometimes violent) and present a major problem. A listing of these reactions is given in Table 3.1 (it is commented that this list is a simplified, condensed version of a complex set of reactions - no attempt is made for completeness as the list functions to demonstrate the reaction types only). The ignition temperature of wood (in air) is 280°C. Table 3.2 compares the ignition temperature of wood with the ignition temperature of other combustible materials/gases in the mine environment and highlights the relatively low temperature that is required to ignite wood.

If wood is heated to a temperature between 250°C and 280°C and kept at this temperature for sufficient time, the loss of mass due to endothermic reactions will be approximately one-third the original mass. When the temperature of wood reaches 320°C less than one-half of the original mass will remain as char. At this point in the combustion process, the compressive strength of the timber has been eliminated and its function as a mine support member is negligible.

Untreated wood is considered a hazard within the mine environment because of the low temperature of ignition and the quick rate at which flame will spread fire on its surface. Flame spread indicies have been established by national standards associations such as:

- Standards Council of Canada; CAN 4-S102;
- British Standards; BS 476, Part 1, 1953;
- American Standards for Testing of Materials; ASTM E162 (E-84-68).

TABLE 3.1 Wood Burning Process

Main Constituents of Wood: Lignin, Hemicellulose, Cellulose

Temperature	Reaction	Occurrance	Products
100°C	endothermic	water of constitution released - wood looses weight	water vapour
100°-200°C	endothermic	Lignin & hemicellulose begin to decompose slowly	non-flammable vapours & gases -carbon dioxide -water vapour -acetic acid -formic acid
200°-280°C	endothermic	Lignin & hemicellulose decompose more rapidly	non-flammable vapours & gases
	(exothermic in special conditions)	initial destruction of cellulose	
280°-320°C	highly exothermic	rapid decomposition of Lignin	gases
		violent pyrolysis of cellulose	tars (levoglucan) (gas + tars + air combustible at 300°C)
500°C	highly exothermic	clear surface on wood begins to burn (prevented earlier in decomposition process by diffusion of air with volatile products)	

TABLE 3.2 Temperatures Needed for Ignition in Air

MATERIAL	TEMPERATURE
Lubricating Oil	200°C - 210°C
Carbon or Char	200°C - 250°C
Timber	280°C - 300°C
Hydrogen sulphide H_2S	315°C
Acetylene C_2H_2	405°C
Hydrogen H_2	570°C
Methane CH_4	680°C

By way of example, the British Standard has four classes of materials:

Class I: Very Low Flame Spread,
<76mm /10 minutes

Class II: Low Flame Spread,
<101mm /1 minute
and
<171mm /10 minutes

Class III: Medium Flame Spread,
<101mm /1 minute
and
>202mm /10 minutes

Class IV: Rapid Flame Spread,
>101mm /1 minute
or
>202mm /10 minutes

The British Flame Spread Index, classifies hardwoods in Class III and softwoods in Class IV. In the United Kingdom, the application of fire-retardant treatments for mine timbers must raise the Flame Spread Index value to Class I.

The ASTM standards have been expanded beyond the Flame Spread Index to include other properties to assess fire-retardant treated woods on characteristics of:

- heat released;
- smoke developed;
- toxicity of combustion by-products.

The methodology of fire-retardant treatment processes for mine timber is based on techniques to prevent or delay the onset of the violent exothermic reactions resulting from the heating of wood. The fire-retardant treatment of mine timber can be accomplished using one of three methods:

- chemical impregnation of salt solutions under pressure;
- surface coating on the wood;
- pre-charring of wood surface.

To minimize the fire hazard in both old and new workings, there are two scenarios for fire-retardant wood treatment processes:

- application to new timber;
- application to standing timber.

The requirements of a fire-retardant for mine timbers as established by the South African Chamber of Mines Research Organization (Hawkins, 1978), are that it:

- should cause difficulty in the ignition of timber and after the onset of ignition it should reduce or prevent the spread of flame across the timber surface. In addition, it should prevent afterglow or sustained combustion on removal of the heat source;

- should be stable to leaching and decomposition by water in liquid or vapor form, of low volatility and able to remain essentially unchanged throughout variations in humidity and ambient temperature;

- should be non-corrossive to other construction materials;

- should not reduce the strength or other working properties of the treated timber and it should be non-toxic. In the event of a fire situation, the retardant should not evolve noxious fumes or dense smoke that would render an escape process more difficult;

- should be applied to the timber in a straight foreward and inexpensive manner;

- should not cause skin irritation.

3.1 Treatment of Timber Before Installation in Mine

Fire-retardant pretreatment processes for mine timber include:

- pressure impregnation of the timber with fire-retardant chemicals;
- surface modification of the timber by precharring.

Chemical Impregnation

The chemical impregnation of the wood by fire-retardant chemicals will generate one of the following effects:

- increase the temperature at which the highly flammable tars associated with rapid pyrolysis are released. This action creates a higher than normal temperature at which the wood "catches fire" due to a local ignition. The chemicals within this classification are normally reserved for the building trades and are not adopted by the mining industry for economic reasons;

- impregnate the wood with chemicals which absorb water (borax or calcium chloride) to ensure a high moisture content of the wood to resist combustion. Most mine environments are humid and the moisture content of mine timbers is high without the application of such chemicals;

- cause the chemical modification of the volatile tar released during combustion (levoglucosan) into char, carbon dioxide and water which reduces the amount of tar to reach the wood-air combustion interface, as well as create a thicker than normal char surface. This extra char thickness further impedes the travel of unconverted tar to the combustion zone and also provides an insulating barrier to unburned wood;

- reduce the temperature at which the pyrolysis reaction gases and vapours are released in an endothermic reaction. Through the low temperature release of the potentially volatile products, lower volumes of these hazardous products are available for release if the wood is exposed to higher temperatures;

- also, the release of these non-flammable gases tend to restrict oxygen from the wood surface and further reduce the chance of combustion.

These last two mechanisms are acheived with organic and inorganic chemical impregnation processes.

Inorganic Chemicals

The major technique used in the fire-retardant treatment of wood is pressure impregnation of the wood with water-soluble inorganic salts. A variety of solution formulations have been developed for this purpose and are presented in Table 3.3 (Browne, 1962).

A major disadvantage of inorganic salt treatments is that the fire-retardant is prone to deterioration by leaching. Also, the delay of combustion in wood at a temperature of 280°c is short-term, extending the time from 5 minutes for untreated wood to 15 - 20 minutes for treated wood (Whillier, 1973).

Organic Chemicals

Organic chemicals have a very limited application within the mining industry because of the high expense these chemicals represent. The chemicals which have been tested and proven successful in a mine environment are (Hawkins, 1978):

- tetrakis hydroxymethyl phosphonium chloride (THPC);
- tris (1-aziridinyl) phosphine oxide 11 (APO);
- dicyandiamide and phosphoric acid;
- urea formaldehyde and phosphoric acid.

These products were originally developed for the textile industry but are useful for wood materials. Organic chemicals are not soluble in water and therefore will not leach from the wood when used in mines.

TABLE 3.3 Dynamic Thermogravimetric Analysis of Untreated Wood and of Wood Treated With Organic Salts (Browne, 1962)

Salt Present In Wood	Content of Salt In Sample - %	Temp. of Onset of Active Pyrolysis °C	Extent of Volatilization of Wood in Sample (%)		
			At 200°C	At 250°C	At 400°C
None - (Untreated Wood)	0	220	0.5	3.7	76
Very Effective Flame Retardants					
Dibasic ammonium - phosphate	40.5	180	4.3	38	50
	11.1	180	3.2	21	51
	2.4	180	2.6	11	57
Ammonium Sulfamate	23.4	180	4.4	45	41
	16.6	180	3.2	37	43
Ammonium Chloride	29.8	150	19	54	54
	18.6	150	14	35	57
	9.0	150	11	23	61
Sodium Tetraborate	11.0	220	0	4.4	50
	1.0	220	0	2.2	57
Moderately Effective Retardants					
Potassium Carbonate	29.2	210	2.5	32	59
	18.6	210	1.9	27	57
	6.7	210	1.6	17	58
Trisodium Phosphate	37.6	200	2.6	15	67
	3.2	200	1.1	9.3	63
Ineffective Retardant					
Sodium Chloride	31.1	220	2.4	7.9	73
	13.5	220	1.9	6.2	70

Major Chemical Impregnation Processes for Mine Timber

There are four major chemical formulations used at the current time in the practice of mine timber fire-retardant treatment by chemical impregnation. These solutions are presented in Table 3.4.

Chemical impregnation processes require that the timber pore structure be open to receive the fire retardant chemical. This requirement necessitates the use of a steam or a vacuum process and constitutes an expensive plant to treat the volume of wood required in most mining operations.

Flame tunnel testing of wood treated with fire-retardant impregnation chemicals used in the mining industry has demonstrated several shortcomings of two existing systems:

- Koppers - NCX is reported (Lee, 1981) to generate a gaseous product, hydrogen cyanide (HCN), when combustion of the treated wood occurs. This gas impairs the capacity of an individual to think and thus the ability to escape from the fire zone;

- Fyreprufe treated timber is reported (Wilde, 1972), (Lee, 1981) to loose its effectiveness after only 15 - 20 minutes exposure to heat. The wood then tends to burn even more vigorously than if it was not treated.

Precharring of Timber Surface

Precharring the wood surface before delivery to and installation in the mine can reduce the fire hazard presented by untreated wood. The charring process causes the release of some of the volatile by-products of wood decomposition in a location outside the mine evironment. Also, the charred surface provides an insulating layer to temporarily protect the unburned wood from local flames (Lee, 1978).

TABLE 3.4 Chemical Impregnation Fire-Retardant Preparations For Mine Timber

Name	Country of Use	Formulation	Supplier
Koppers-NCX[1]	USA	Organic Formulation	Koppers Co. Inc.
Fyreprufe	UK (NCB)	inorganic formulation .89% ammonium sulphate . 5% ammonium phosphate . 2% sodium chromate . 4% sodium fluoride	National Coal Board
Pyrolith M[2]	South Africa	.90% ammonium sulphate . 5% ammonium phosphate .wax additive to inhibit leaching & plant corrosion	Hickson Timber Preservation (Pty)
Pryolith KA	South Africa	ammonium sulphate based (see: Pyrolith M) with more ammonium phosphate	" "

1 Koppers-NCX - is a proprietary resin system similar in structure to melamine type polymers. An inorganic phosphate is blended with the resin precursor prior to wood treatment. NCX contains no halogens or sulphates. It is leach resistant and suitable for exterior (underground) use and is of low hygroscopicity. Tests have shown that NCX treated wood has exhibited increased decay resistant properties.

2 HL & H Mining Timber markets a product "Flametard" which is a registered name for a PYROLITH M plant, chemical formulation and treatment cycle licensed from Hicsons Preservation (Pty) Ltd.

3.2 Treatment of "Standing Timber"

Surface treatment of wood by spraying or painting a surface coating (mainly for "standing timber" in mines) has the combined effect to:

- reduce the heat which is transferred to the wood from a local fire source;
- seal the surface of the wood and thereby prevent the release of potentially flammable gases, vapours and tars to open flame.

Chemical Surface Coating

The chemical surface coatings of mine timbers is not as effective a fire-retardant treatment as the chemical impregnation process.

"Surface coatings, even if they remain adherent to the timber, cannot in practice give protection against such combinations of intensity and duration of heat energy, and it is recognized that their role in mining consists of preventing ignition of timber by small, sustained sources of heat, and reducing the rate of development and spread of fire." (Wilde, 1968)

Despite these restrictions, chemical surface coatings of mine timbers are able to improve the rating for flame spread from Class III or IV (depending on the type of wood) to Class I.

Certainly the general class of chemical sealants which are available to the mining industry extend well beyond those which are suitable as a fire-retardant surface coating material. Special properties which are required of coating materials include:

- mechanical durability to withstand possible ground movement;
- tolerate high humidity levels;
- tolerate leaching by acidic mine water;
- tolerate running water;
- must adhere well to mine timbers even when dusty or wet.

This review will consider only those coatings which have been tested in a large scale flame test facility or in a mine and are currently used by the mining industry as a fire-retardant coating for mine timbers.

In the West German coal mines of the 1940's, a sodium silicate solution was sprayed in a 0.43 mm thick layer on mine timber to give it an effective fire-retardant coating (Wilde, 1972). Initial work in Great Britain by the National Coal Board (NCB) employed a mixture of sodium silicate, sand and limestone dust (ratio of 3:4:4) in thickness of 4.25 mm for a fire-retardant coating, (Guider, 1954). A NCB improved formulation of sodium silicate, limestone dust and water (ratio 1:4:1) in a coating thickness of 1.1 mm for hardwoods and 3.2 mm for softwoods provided an effective fire-retardant coating to mine timber for many years, (Wilde and Roberts, 1968). Recently, however, the availability of non-flammable mine sealants have received more attention than these traditional sodium-silicate formulations.

Non-combustible Mine Sealants as a Fire-retardant Coating for Mine Timber

The technology of mine sealant materials has greatly expanded in the last decade. In a CANMET report (Associated Mining Consultants Ltd., 1984) on mine sealants, a total of 26 mine sealant formulations were investigated, some of which have been employed as a fire-retardant coating material for mine timbers. The available mine sealants can be grouped as follows:

- gypsum based sealants;
- cement based sealants;
- others
    - rubber latex,
    - urea formaldehyde,
    - phenolic resins,
    - bentonite.

Table 3.5 is a brief summary of mine sealants which have been employed for fire-retardant coatings. Flame tunnel tests on

TABLE 3.5 Examples of Mine Sealants as Fire-Retardant Coating of Mine Timbers

Sealant Type	Product	Sample Proprietary Formulation	Manufacturer
Gypsum	1. Gypsum + additives	Hardstop* Hardstem	British Gypsum Ltd.
	2. Gypsum + exfoliated vermiculite	Gypseal	British Gypsum Ltd.
	3. Gypsum + fiberglass	N/A	N/A
Cement	1. Perlite + ground limestone + Portland Cement + additives	Strong-Seal	Strong Seal Systems Inc.
	2. Delaminated exfoliated vermiculite + Portland Cement and Whiting and additives	Mandoseal	Mandoval Ltd.
	3. Portland Cement + mineral wool	N/A	N/A
Other	1. foamed sodium silicate	N/A	N/A

* not recommended as a fire-retardant coating by NCB (Wilde, 1968).

these products have shown that the required thickness of the coating for fire-retardant purposes is considerably less than for sealant purposes. It is reported (Wilde, 1968) that:

> "It appears that if sealant coating materials could be applied to timbered roadway linings...they might offer better protection against fire than impregnated timber."

One major problem with sealants being used as a fire-retardant coating of timber is that timber not exposed to the tunnel opening is not coated by the spray or paint application. Consequently, there will remain a continuous, unprotected wood surface on the backside of the tunnel in contact with the rock surface. This problem may be exacerbated by the fact that the sealant may trap concentrations of methane behind the wood lining thus increasing the potential fire hazard in the event of an ignition. A further problem which has been experienced using sealants as a fire-retardant coating is that they tend to fracture and spall from the wood if the wood fractures or warps during service (Wilde, 1968).

Polymer Based Coatings

Polymer basedcoatings consist of a polymer binder which adheres an extremely effective halogenated fire-retardant compound plus a mineral filler to the surface on which it is applied. THis type of coating is used in the USA and Europe; however, the NCB has not approved its use in British coal mines due to the possible combustion of minor amounts of the polymer and the subsequent release of noxious fumes, (Wilde, 1972).

Intumescent Paint Coatings

There exists a large variety of commercially available paints which will expand when heated to form a foam-like film on the wood surface. This film acts in two ways:

- it insulates the wood from the heat source;
- it prevents any volatile by-products generated by the pyrolysis of wood from reaching the heat source.

The intumescent nature of these paints is accomplished by the use of special expanding organic compounds.

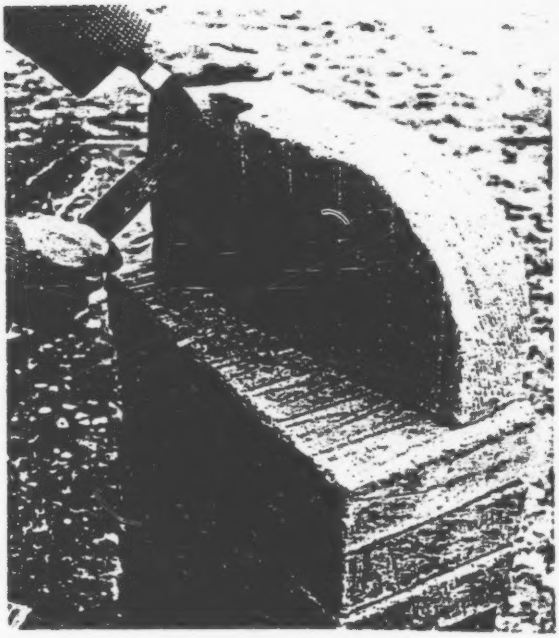
Intumescent paints are formulated for building interior applications and will not tolerate a harsh mine environment. In work conducted by Factory Mutual Research Corporation (Lee, Croce and Newson, 1981) the comparable efficiency of intumescent paint to Koppers-NCX inpregnated treatment (on a basis of reduced fire propagation, fuel generation, heat, carbon monoxide and smoke) would indicate the potential usefulness for such a product to treat "standing" mine timber. Further research in this area should be encouraged.

4.0 CONSTRUCTION MATERIAL ALTERNATIVES

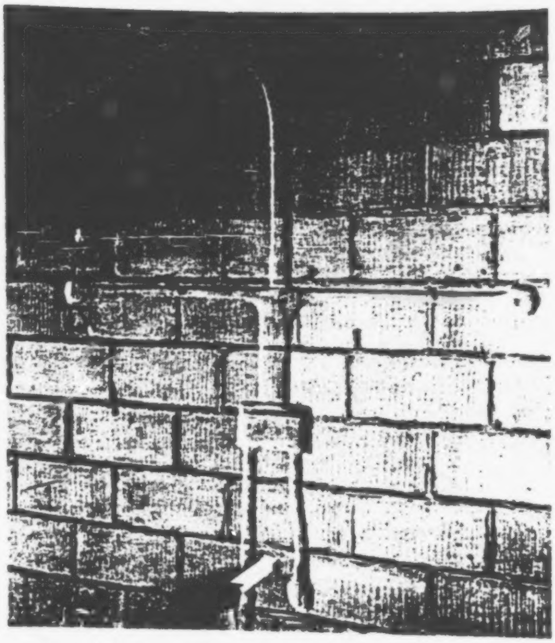
Construction materials and construction techniques currently used by the mining industry as an alternative to wooden structures underground are listed below. Many of the technologies identified in this listing are discussed in more detail in later sections of this report. The list of construction materials and techniques includes:

- mortared concrete blockwalls (normal weight, light weight aggregate and autoclave aerated concrete block can be used);
- concrete block with fiberglass reinforced surface bonding mortar which eliminates the need for mortared joints in the blockwall construction (Burrell Mining Products);
- wire mesh panels sprayed with multi-layers of a fiber reinforced shotcrete (Chironis, 1975) or a mine sealant (Artler, 1974) have been used to construct stoppings and isolation rooms;
- sheets with light steel frame construction can be used to erect operator enclosures or isolation rooms;
- fire and ventilation doors of steel sheet construction set in a steel frame and erected in a mortared joint and sprayed concrete block wall have been investigated by the USBM, which has proposed design guidlines for noncoal mine doors (Bickel, 1981);
- ventilation regulators can similarly be constructed of steel sheet in a steel frame;
- pneumatically placed anhydrite and wire mesh reinforcement has been used to construct fire proof stoppings (Blades, 1974);
- rail ties constructed of formed metal or prestressed saran latex modified ordinary portland cement (Dow Chemical Co., 1981) are used.

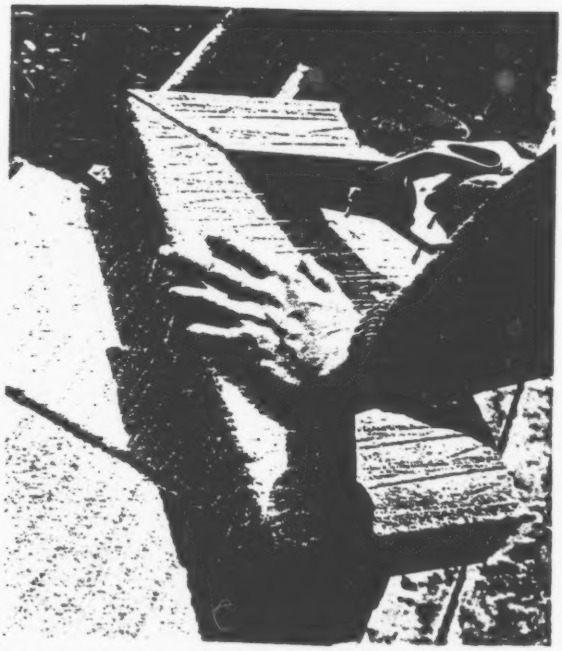
The major advantage for wood in underground construction is that is can be readily shaped with minimal effort at the job site. Steel structures would necessarily be fabricated on the surface and transported in finished form, or in components which would be bolted together at the job site, to minimize welding and cutting in the underground environment. Normal weight concrete block can be shaped and sized but with less accuracy and flexibility than wood. Autoclave aerated concrete block can be shaped and contoured in much the same manner as wood, with limited hand tools, and would therefore constitute an excellent construction material for the replacement of wood, Figure 4.1. Sprayed concrete, mine sealant or pneumatically placed anhydrite will provide a construction technique which is very flexible.



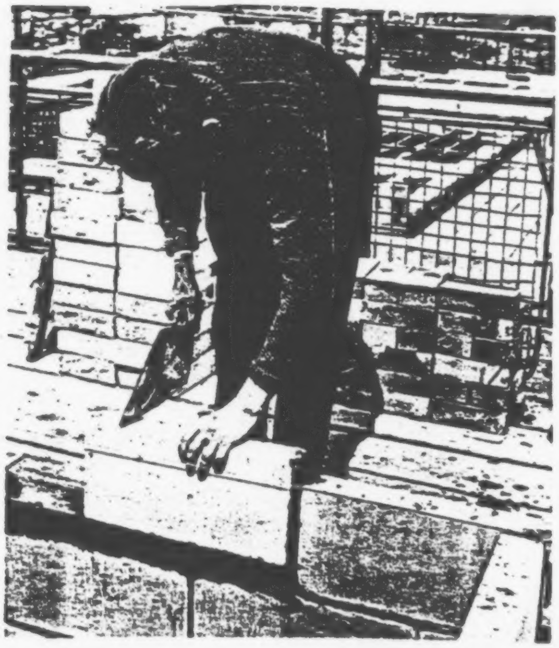
Chasing aerated concrete blocks with a scutch hammer.



Aerated concrete blockwork ensures easy compliance with the limitations for chasing imposed by building regulations.



Sawing aerated concrete blocks.



Easy handling of aerated concrete blocks.

Figure 4.1 Aerated Lightweight Concrete Block Construction showing the ease with which it can be shaped and contoured.

5.0 ROADWAY LAGGING MATERIALS

The use of wood lagging in mine roadways constitutes a high-risk fire hazard due to the development of a continuous flame path through extensive areas of a mine. This hazard can be eliminated through the use of alternative lagging materials which include:

- steel lagging products;
- cementitious lagging products (cast in place and precast units).

These alternative technologies will eliminate the fire hazard created by wood lagging in mine roadways and in many cases will also improve the geotechnical integrity of the roadway.

The generally accepted criteria which constitutes a product as a good lagging material include the following items; it must:

- provide security against falls of stone and coal;
- be easy to handle and install;
- not be bulky in transport;
- have a high load-to-weight ratio;
- be cost effective;
- be fire resistant.

Ideally, a lagging material will also provide two more functions in addition to restraint of loose stone and coal. The lagging material should occupy the void between the support and the roadway profile so as to provide an early resistance to strata pressure. Also, the lagging material should eliminate potentially damaging point loads on the main support members through a uniform distribution of the ground stresses.

5.1 Steel Lagging Products

Two relatively well known steel products used for lagging materials in geotechnical tunnels and mining roadways are corrugated steel sheets and steel liner plates (Bullers & Burns, 1980). Liner plates are very costly; however, and can be justified only in the event of working in very unstable ground conditions.

Welded Steel-Mesh Panels

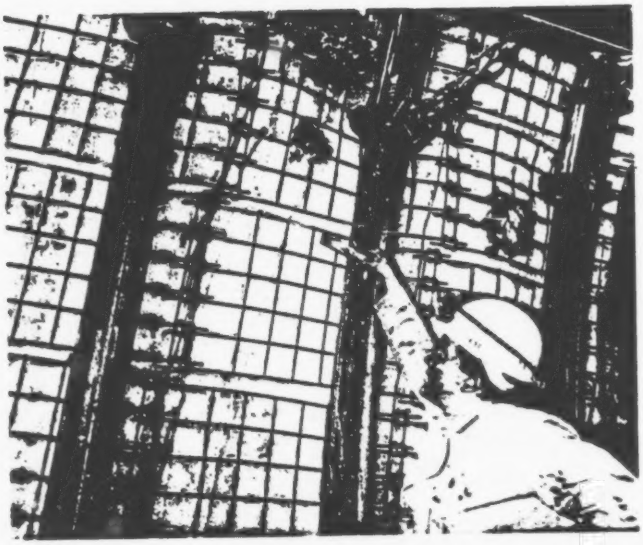
A steel product known as welded steel-mesh lagging (wire-mesh panels) is used extensively in European coal mines; however, there is only a limited application of this product in North American coal mines. A variety of wire-mesh panel designs have evolved since being first introduced in West Germany in 1955.

Wire mesh panels are spot-welded meshes of cold-worked, drawn wire with hooked ends designed to engage the support arches (back-lagging mats) or to engage previously laid panels (extensible mats). The general appearance of this product is shown in Figure 5.1.

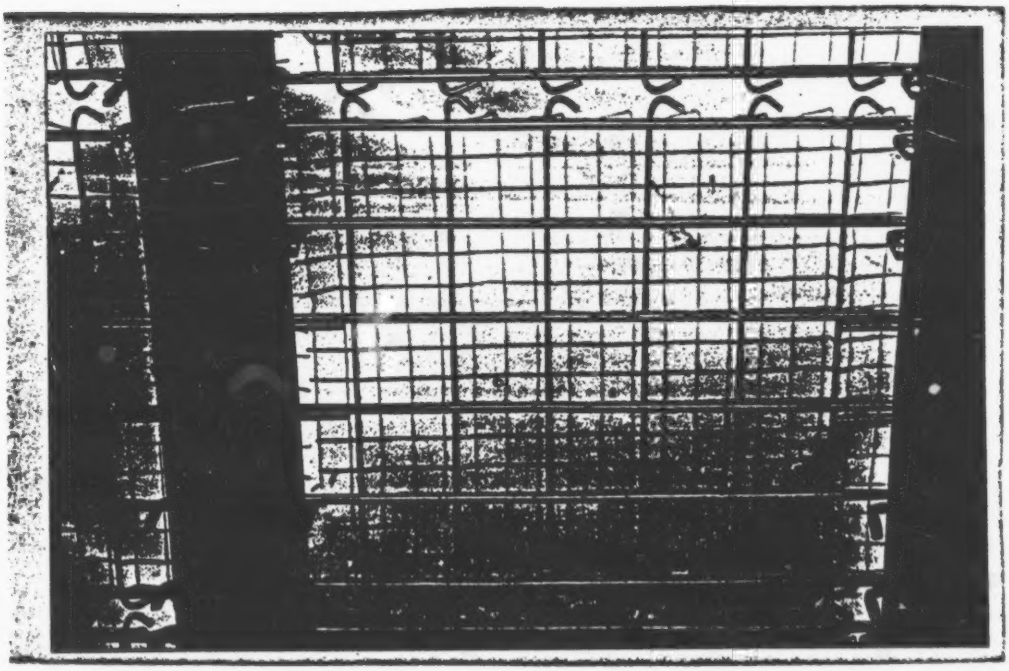
Work done by Ruhrkohle AG(RAG) (Zillessen and Bonk, 1982) presents an appraisal of the ten available mat configurations identified in Figure 5.2. The results of the testing is given in Table 5.1. A series of load/yield diagrams were also presented in the RAG evaluation and are included in Figure 5.3. The general conclusions derived from the RAG work are:

- the load-bearing capacity of extensible mats is three to five times greater than most back lagging mats (excluding style E);

- the load capacity of the back-lagging mat depends on the size and number of the mesh rods and also extensively on the hook configuration;



Extensible Mat



Back-lagging Mat

FIGURE 5.1 Wire Mesh Panels used to Lag a Mine Roadway

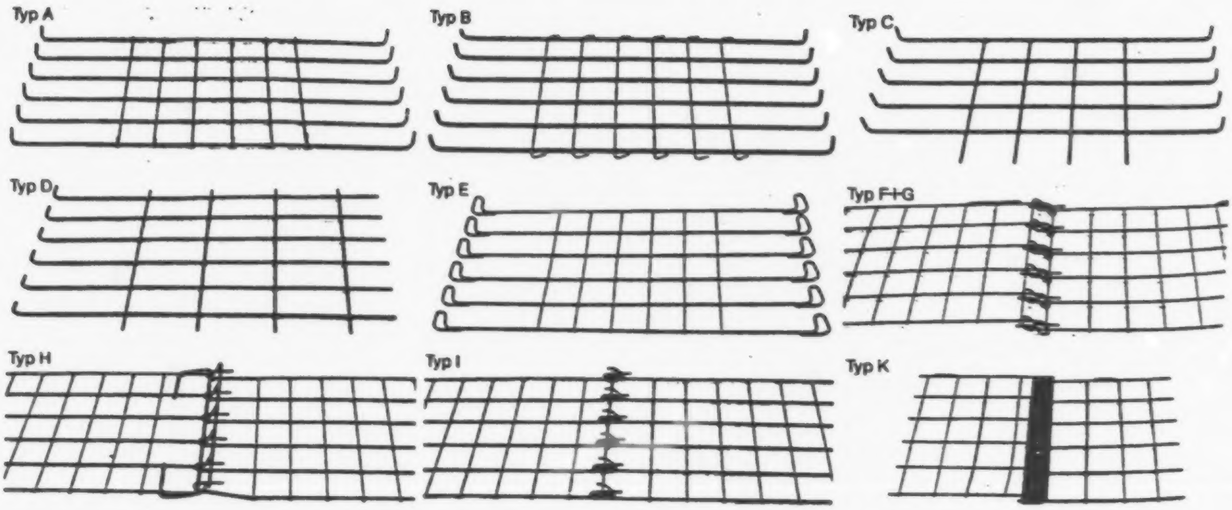


FIGURE 5.2 Ten Wire-Mesh Panel Configurations (Zillessen and Bonk, 1982)

TABLE 5.1 Test Results on Ten Wire-Mesh Panels (Zillessen and Bonk, 1982)

Type of mat	Rod thickness in mm		Number of rods		Layout of hooks	Bearing capacity F_{max} in kN		Flexion at F_{max} in mm		Weight of mat in kg	$\frac{F_{max}}{Weight}$ in $\frac{kN}{kg}$ at a 5-mm gap
	length-wise	across	length-wise	across		free-resting	5-mm gap	free-resting	5-mm gap		
Back lagging											
A*	7.8	4,7	6	6	double sided	5.5	29	290	167	3,0	9,6
B	7 × 11	4,7	6	6	double sided	10,2	45	170	117	4,2	10,7
C	9,6	7,8	5	4	double sided	7,4	37	270	161	4,0	9,2
D	9,8	7,8	6	4	one sided	8,5	17	130	238	4,8	3,5
E	7,9	4,6	6	5	double sided	57,0	161	215	244	3,0	53,7
Extensible											
F	7,0	4,8	6	6	—	3,6	132	145	334	2,6	50,8
G	8,0	4,6	6	6	—	4,1	177	205	359	3,2	55,3
H	8,0	4,7	6	6	—	5,0	124	170	216	3,5	35,4
I	8,0	4,6	6	7	—	4,6	111	200	195	3,0	37,0
K	7,0	4,6	6	7	—	4,5	72	140	167	3,0	24,0

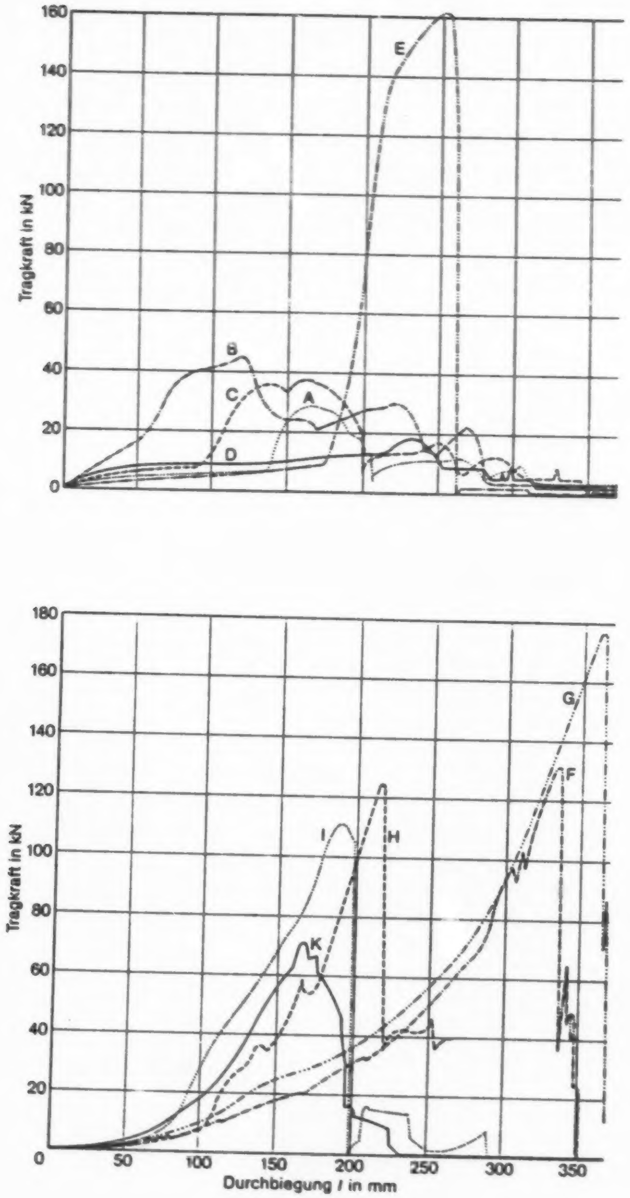


FIGURE 5.3 Load/Strain Diagrams for Weld-Mesh Panels (Zillessen and Bonk, 1982)

- the single hooked back-lagging mat has a poor performance due to sliding of the unhooked end and consequently provides limited resistance against ground pressures (Note: This type of mat is currently employed by CBDC on trial);
- the load bearing capacity of back-lagging mats is only improved very slightly (20%) by over-lapping and this practice is deemed uneconomic though it is used quite frequently;
- though superior strengh is provided by the extensible lagging mat, the installation of the same is more difficult especially in shot-fired headings where damage to the ends of the mat, to be connected, may occur.

An economic evaluation of wire-mesh lagging is reported (Whitworth, 1983) which states that with the current highly automated production lines for wire mesh lagging (as used by Wilhelm blaser GmbH & Company, Kamen) Figure 5.4, wire mesh lagging is only half as expensive as timber lagging or corrugated steel sheets.

Wire-mesh panels do not replace the requirements for a strut support between arches. Extensible mats provide no lateral restraint to the arch supports as there is no connection between the arch and the mat. Although back-lagging mats are hooked around the flange of the arch support, they provide limited strength as a strut member to restrict lateral deformation of the arch supports. Consequently, when using wire-mesh panels, strut supports between arches are required unless backfilling procedures are used in conjunction with the mats. This strut requirement can be provided through the use of conventional techniques:

- timber struts fitted into the web of the arch;
- lengths of angle iron notched to hook around the RSJ flange;

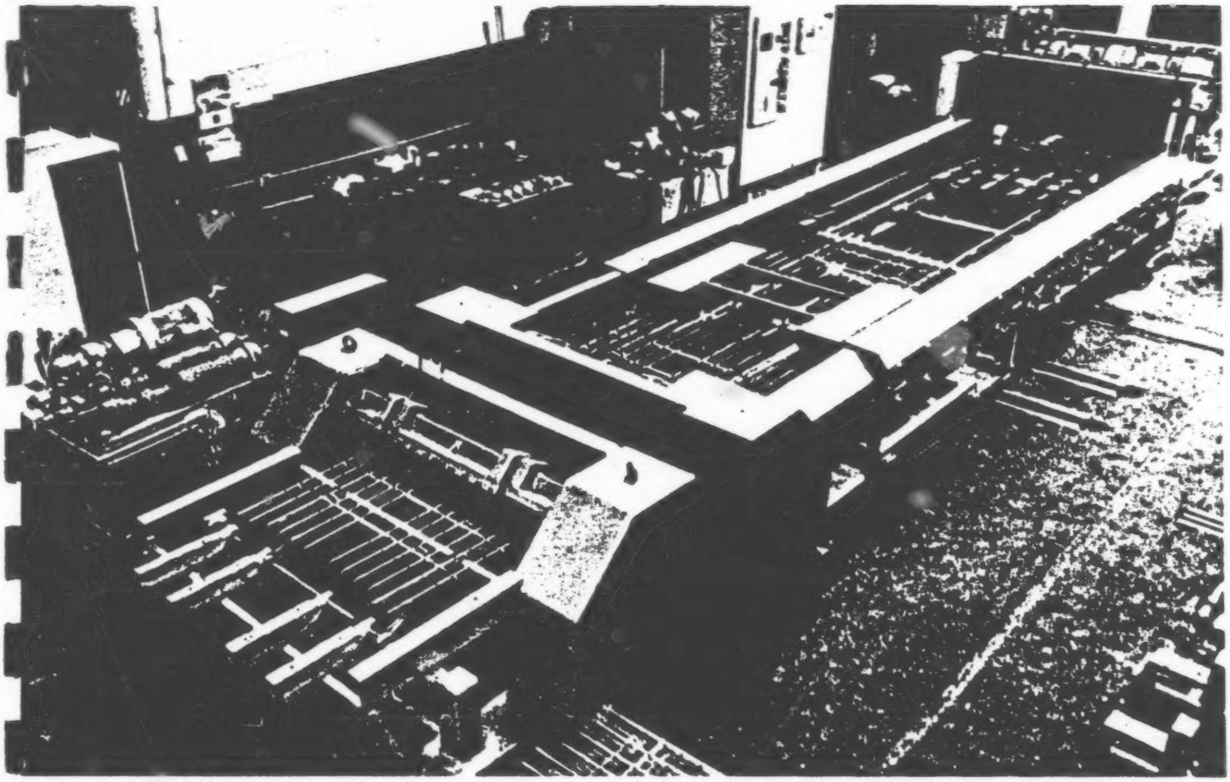


FIGURE 5.4 Highly Automated Production Line for Wire Mesh (Wilhelm Blaser GmbH Co.)

- sections of hollow tubing which bolt onto special recepticals fitted to the RSJ section.

When supports are backfilled with a cementitious material in conjunction with wire-mesh lagging, the edges of the arch sections are restrained against lateral movement by the backfill material (Arauner, 1985).

Strutlag

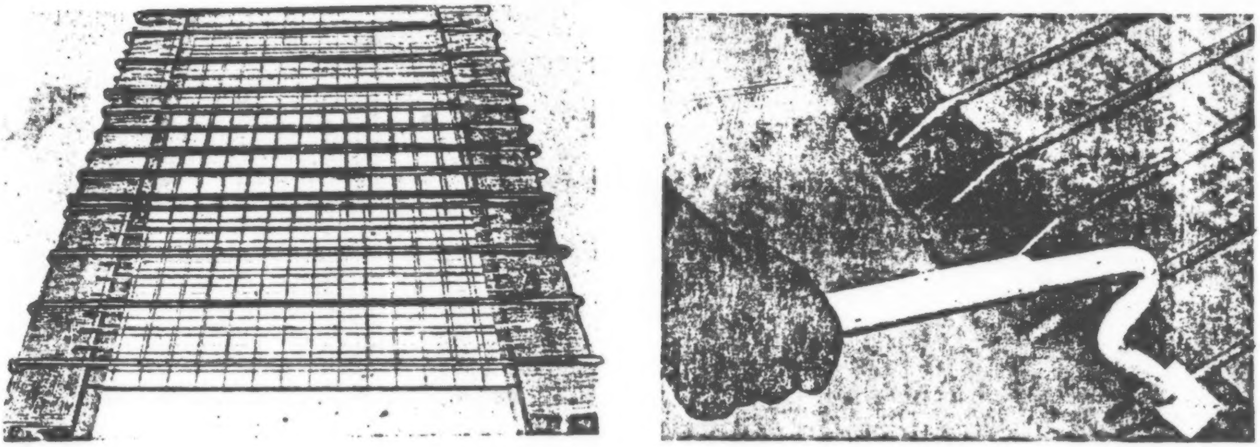
Strutlag is a product which is reported (Anon.(a), 1971) to function as both a lagging mat and a strut member for roadway support requirements.

Strutlag consists of a series of horizontal 8 mm diameter steel rods spaced at 10 cm centres with sheets of 10 mm diameter wire mesh (standard panel dimensions) overlaid and welded to these sheets. This product is constructed in 50 cm wide panels of lengths sufficient to span the distance between support settings.

During the installation, the 8 mm rods are bent around the the outside flanges of adjacent arches thereby tying them together, Figure 5.5. The strutting capacity of Strutlag, when applied to several standard NCB arch girder supports, is given in Table 5.2. Strutlag can be purchased with the 8 mm rod spacing and mesh aperture modified to meet local ground conditions.

Rock Bolts and Wire Mesh

Rock bolts have been used in coal mines as both the main support system and as a supplement to conventional support systems (mainly steel arches). Extensive work on rock bolt systems in room and pillar coal operations in the US and longwall coal operations in France and Germany have generated extensive design criteria for this support method. In France and Germany, experimental work on deep mine roadways supported solely by rock bolts (fully resin grouted) have



(a) Standard 50 cm wide panel of Strutlag having 6 rods at 10 cm centers.

(b) Bending the end of an 8 mm horizontal rod around the rear flange of an established support using standard bending tools.

FIGURE 5.5 Strutlag (Anon(a), 1983)

TABLE 5.2 Strutting Value of Strutlag When Applied to Standard NCB Arch Girder Profiles (Anon(a), 1983)

Arch Profile feet	Circumference in feet	No. of Panels per Arch	No. of Rods per Arch	Tension in tons
10 × 9	18·0	11	66	30·5
11 × 9	20·0	12	72	33·3
12 × 10	21·5	13	79	36·0
13 × 10	22·5	14	84	38·7
13 × 11	24·5	15	90	41·5
14 × 11	25·0	15	90	41·5
15 × 11	25·5	16	96	44·3
15 × 12	27·5	17	102	47·5
16 × 12	28·5	17	102	47·5

been successful (Morris, 1981) (Tinchon and Degean, 1981) and (Josin and Gouilloux, 1978). Experimental work in the UK by the MRDE (Barrett, 1981) has been conducted on gateroad drivages for both advance and retreat longwall systems using full-column resin-anchored rock bolts as a supplement to conventional steel arch supports. The reported benefits of this work have been summarized as follows (Barrett, 1981):

- Improvement in roadway strata conditions:
  - stabilization of ground around a roadway;
  - reduction of roadway secondary closure;
  - improved conditions at T-junctions;
  - safer conditions for the salvage of roadway material.

- Savings in roadway support costs:
  - reduction in the density of steel arches;
  - in retreat longwall mining this system often permits the reuse of gateroads.

Any further description of rock bolting systems, design criteria and merits of the system will not be pursued under this report. It is commented, however, that with the advantages of rock bolting being reported internationally, it may provide similar economic and operational advantages within the CBDC Coal Mines. Consequently, further investigations into this matter may be warranted.

The introduction of rock bolting in coal mines serves to highlight a lagging product which can replace wood lagging or corrugated steel. The use of wire mesh pinned to the rock bolt with washer plates provides a very effective lagging material, Figure 5.6. Wire mesh is available in both rolls and panels with an extensive range of wire diameter and mesh size, Figure 5.7.

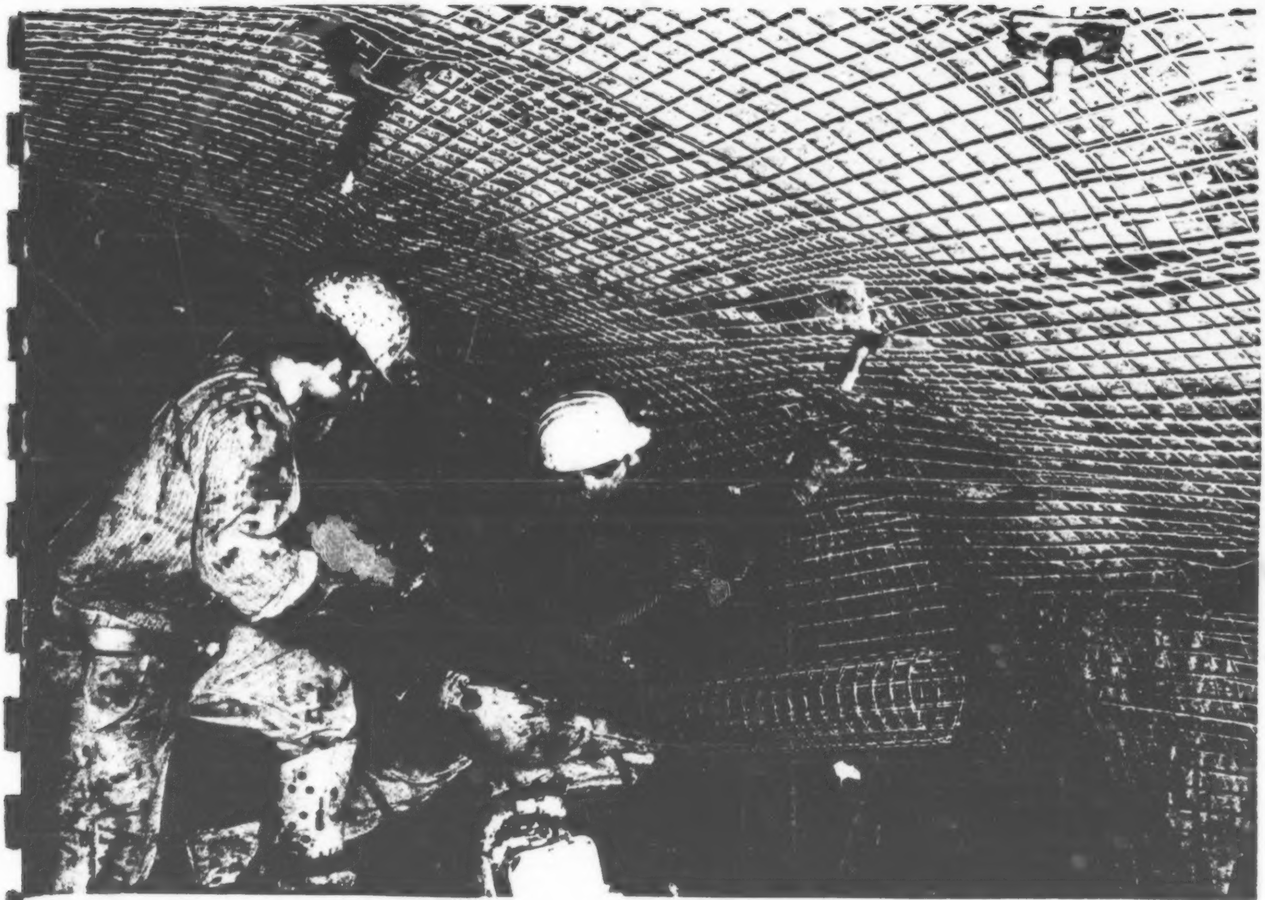
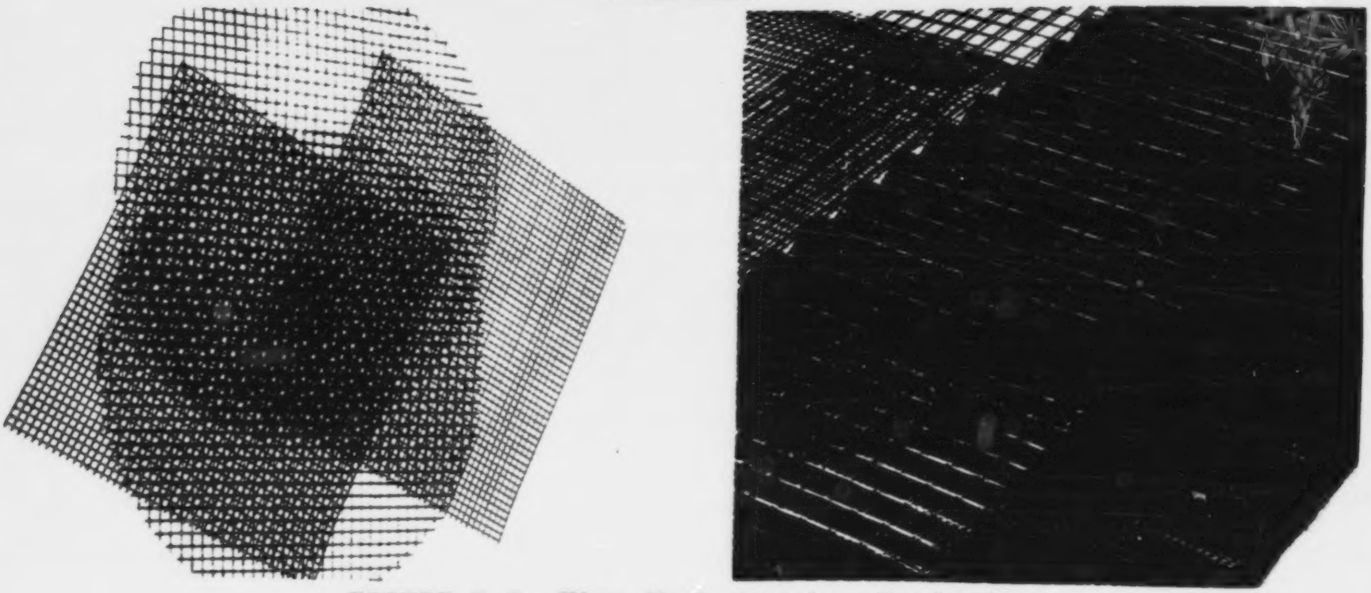


FIGURE 5.6 Roof Bolting and Wire-Mesh Screen Lagging in a Coal Mine Roadway

Rolls

Mesh Size	Diameter Fr. - To.
3 x 3mm	0.4 - 0.6mm
5 x 5mm	0.4 - 0.8mm
6 x 6mm	0.4 - 1.2mm
8 x 8mm	0.4 - 1.5mm
10 x 10mm	0.4 - 1.5mm
12 x 12mm	0.4 - 1.5mm
16 x 16mm	0.5 - 2.0mm
20 x 20mm	0.5 - 2.0mm
25 x 25mm	0.5 - 2.5mm
40 x 40mm	0.8 - 2.5mm
50 x 50mm	0.8 - 6.0mm
75 x 75mm	1.0 - 6.0mm
100 x100mm	2.0 - 6.0mm
150 x150mm	2.0 - 6.0mm



PANELS

FIGURE 5.7 Wire Mesh Lagging Products

It is reported that the wire mesh lagging is approximately 75 percent cheaper than corrugated steel per unit area (Barrett, 1981). The replacement of wood lagging has similar economic advantages plus it represents a reduction of combustible material in the mine.

A further extension to the rock bolt and wire mesh system (support and lagging) is the alternative to shotcrete the tunnel profile using the wire mesh as reinforcing steel. This technique provides additional strength to the support system and will be discussed in more detail in the section "Sprayed Concrete".

5.2 Cementitious Lagging Products

The use of cementitious materials as lagging products has been accomplished through both cast-in-place and precast techniques. The technologies identified in these catagories will be discussed in the following sections.

Cast-In-Place Techniques

There are several techniques to apply cement using cast-in-place methods, to replace wooden lagging and backfilling timber for roadway support. These techniques will be described as follows:

- complete roadway backfilling;
- partial roadway backfilling;
- sprayed concrete on the roadway profile.

Complete Roadway Backfilling

The mechanical backfilling of roadways has been practiced in West German coal mines since 1971. The inception of this practice was necessitated by the extreme roadway deformations (25 - 40%) (Eulgen,1985) generated by increased mining depth and enlarged roadway profile. The advantage of the backfill system is a significant reduction in roadway deformation, which is attributed to (Arauner, 1985):

- high-early strength support permitting very limited strata movement;
- uniform load distribution on the support arches with the elimination of destructive point-loads;
- improved support/strata interaction and therefore the elimination of destructive bending stresses in the supports;
- an increased support strength generated by the cemented backfill lining (self-supporting capacity of the lining);
- improved strutting effect due to the slight embedment of the arch flange in the backfill (the lagging should not interfere with this strut support mechanism).

The techniques which are used for roadway backfilling can be classified as hydraulic or pneumatic, based on the method used. Both techniques supply a cement based placement backfill material between the rock surface and a wire mesh lagging panel covered by a fine mesh or net (plus a fabric cloth for hydraulic backfilling) to retain the stowed material. A wide variety of cementitious materials have been used for roadway backfilling. If roadway backfilling is introduced in mines using cementitious products for other functions (e.g. packwall and stopping construction), the existing cement products are usually adopted, as long as it is a high-early strength cement.

Natural anhydrite has been used for the purpose of roadway backfilling, employing its natural cementing properties when wetted (Gaubig, 1985) (Anon(b), 1983).

A recently announced material for roadway backfilling, reported by the West German Federal Ministry for Research and Development, is a light weight grout or "foamed grout" (Schumann, 1985). The material is a cement grout product to which additives to promote the aeration process are premixed. The aeration is done using normal compressed air and a mix pipe equipped with a high-speed vane mixer located at the discharge, Figure 5.8.

The degree of aeration can be controlled at the mix pipe. The major advanatage of light grout is the reduced bulk density which generates a reduction in volume of grout required to perform the backfill function, Table 4.3. One disadvantage of this system is that the grout is not a high-early strength material when aerated. The cement product used in the West German testing is a proprietary mix known as "Wulfrath - Thyssen backfilling grout, extra light." The NCB has also developed an aerated grout product, "Acqualight," for roadway backfilling.

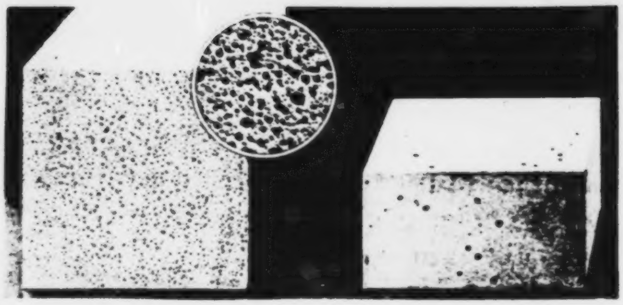
The National Coal Board in conjunction with Pozament Cement has developed a thixotropic grout material, "Archfill7," designed for roadway backfilling. This product is a mixture of OPC, aluminium sulphate and a large quantity of fly ash to minimize the cost of the product.

Investigations have also been conducted in West Germany on the use of fly ash cements as a roadway backfilling product. It is also commented that the patent on "Flashpack" in the UK does indicate the fly ash cement material used for monolithic packs will be suitable for cavity filling and roadway backfilling.

The technology developed in roadway backfilling is extensive and further discussion is not warranted in a report that is to consider alternate technologies for wood replacement. It is commented that the replacement of wood lagging with appropriate wire mesh panels and where necessary supplemented with roadway backfilling would reduce wood usage and generate improved roadway support. Consequently, further investigation of this subject may prove of significant benefit to the CBDC coal mines.

Partial Roadway Backfilling- Grout Envelopes

Partial backfilling of roadways is used when complete backfilling is not economically justified or when complete backfilling is to be done on a delayed basis and early support is required. This technique uses a textile tube or envelope which is fitted behind the arch support and filled with a hydraulic grout, Figure 5.9. Suppliers of endless textile tubing for grout envelopes used in Europe include:



Foamed light grout of bulk density 1.0 t/m (left) and normal grout (right) each made with the same amount of material

Static mixer, installed at discharge end, for foaming light grout with high-pressure air

FIGURE 5.8 Foamed Grout for Complete Roadway Backfilling (Schumann, 1985)

TABLE 5.3 Reference Values For Light Grout

Grout Bulk Density t/m	Volume of Air Voids %	Filling Factor t/m	Compressive Strength N/mm
0.8	60	0.62	1 to 4
1.0	50	0.77	3 to 8
1.2	40	0.92	6 to 12
1.4	30	1.08	10 to 24

- Gesteins-und Tiefbau GmbH (W. Germany) (endless woven-textile tubing) - Bullflex (Anon(b), 1983)
- Butyl Products Ltd. (U.K.) (woven polyester treated with Antiblaze 19) - Grout Envelopes (Wood, 1984)
- Bondina Ltd. (U.K.) (non woven 100%, 2.8 denier thermouyl PVC fiber with acrylic bonding) - Grout Envelopes (Wood, 1984)

The standard grout envelope is 380 mm to 460 mm in width and is placed symmetrically behind the steel arch support.

The cement mix used for grout envelope filling includes equal parts of OPC and pulverized fly ash, with 5% long chain polymer and 5% high alumina cement supplied by Pozament Cement Ltd. (Wood, 1984). The Bullflex system uses any hydraulically setting material. Partial backfilling is not designed to replace complete backfilling; however, it does provide an immediate, relatively cheap and quickly installed support reinforcement technique.

A variety of grout filled envelope designs, in addition to the envelope fitted symmetrically behind the arch, as previously described, were investigated (MRDE, 1978). these designs included:

- envelopes used in conjunction with Weldmesh lagging;
- wide envelope bags;
- tadpole bags.

An effective arch support backfill and roadway lagging system is reported by the MRDE (1978) using standard grout envelopes placed symmetrically behind the arches in conjunction with Weldmesh laggingbetween arches, Figure 5.10. Trials with multiple envelopes to completely line the roadway were unsuccessful due to excessive deflection in the area of the central envelope, Figure 5.11.

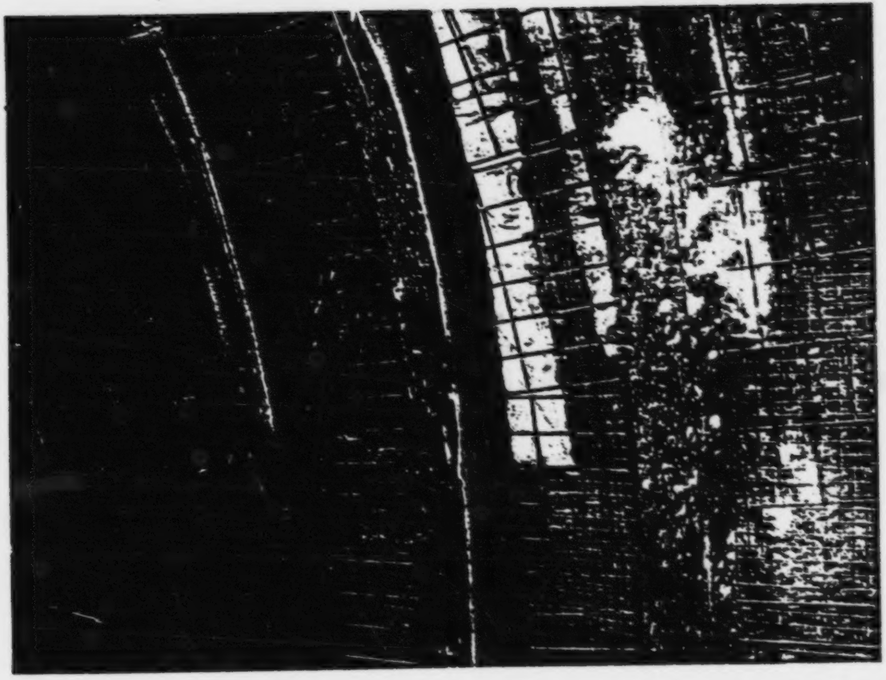


FIGURE 5.9 Grout Filled Envelope in Place Behind Arch. Note the Wire Mesh Lagging Which is Backed By A Wire Net Material. (Photograph Taken Prior to Shotcrete) (Wood, 1984)

The tadpole bag system comprises two bags stitched together; a standard bag (380 mm - 460 mm), referred to as the head bag, located behind the arch and a tail bag which is stretched to the adjacent arch to form a continuous envelope between arches, Figure 5.13. the tail bag is secured against the next arch using a standard single bag or the head bag of the next tadpole envelope, Figure 5.14. The head and tail sections of each bag are filled with grout through separate nozzles which accommodates the sequence of grout filling as described in Figure 5.14.

Excessive deformation of the tail bag was overcome by stitching the bag at 310 mm intervals and thereby creating a quilted effect when filled with grout. This technique minimized deflection and reduced the quantity of grout required to fill the tail. Encouraging results from surface trails of this sytems are reported (MRDE, 1978) and underground trails were recommended. Sprayed Concrete

Sprayed concrete (more commonly referred to as shotcrete) has been used in coal mine applications in the following situations (Felstkorn, 1985):

- multiple-shell application with steel mesh or lattice beam reinforcement to provide a primary support lining in mine openings. These openings include shaft stations, pit bottoms, mine structures close to the shaft and stone drifts not subjected to excessive convergence (Feckler, 1985);

- roadway consolidation to provide temporary support;

- a protective coating on steel supports to prevent corrosion or as a repair coating to compensate for weakened support steel arches due to corrosion;

- a sealant for packs and stoppings.

Within this section of the report on lagging, the use of shotcrete as a tunnel lining material, either by itself, reinforced with weld-mesh or lattice beams, or in conjunction with rock bolting represents a replacement technique for wood

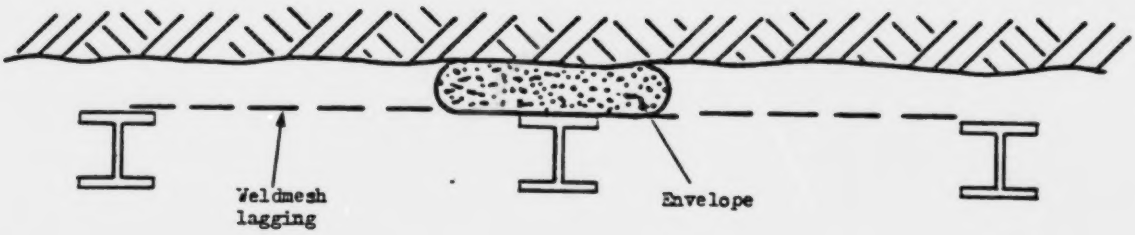

Weldmesh lagging
Envelope

FIGURE 5.10 Single Envelope and Weldmesh (MRDE, 1978)

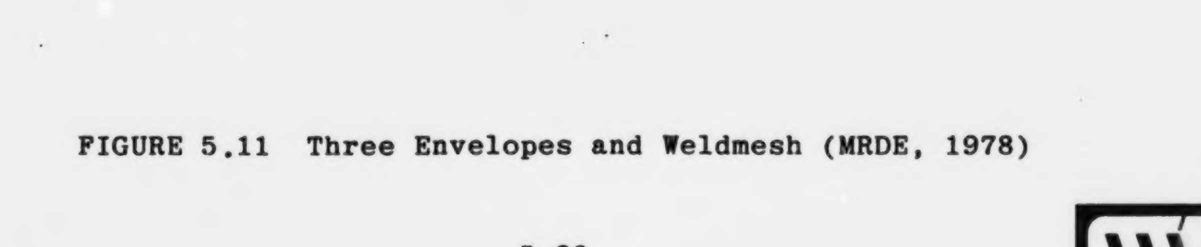

380 mm wide envelope
Bulge Area
610 mm wide envelope
460 mm wide envelope

FIGURE 5.11 Three Envelopes and Weldmesh (MRDE, 1978)

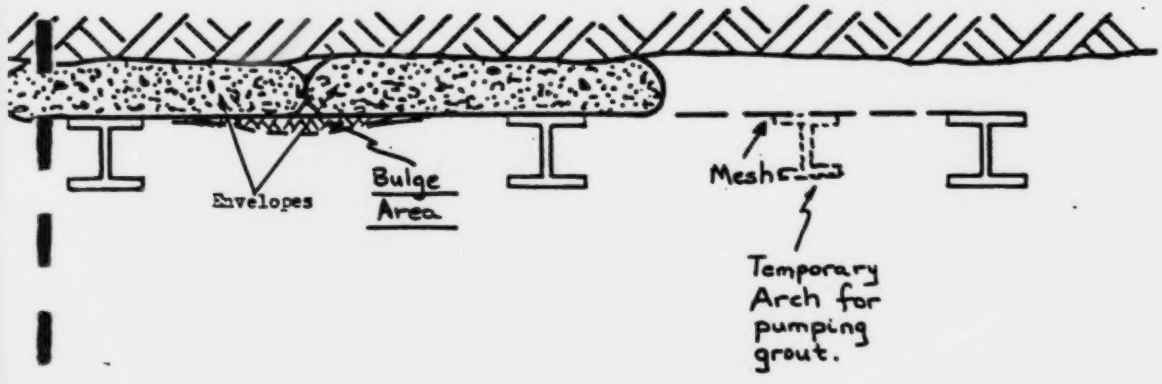
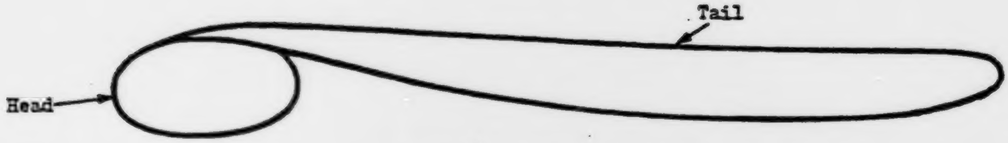
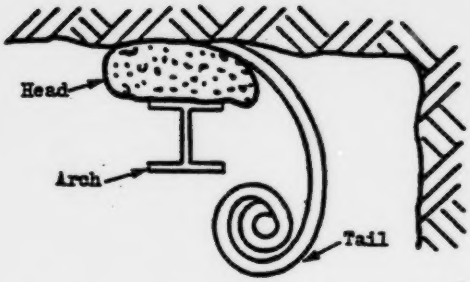

Envelopes
Bulge Area
Mesh
Temporary Arch for pumping grout.

FIGURE 5.12 Two Envelopes and Weldmesh (MRDE, 1978)

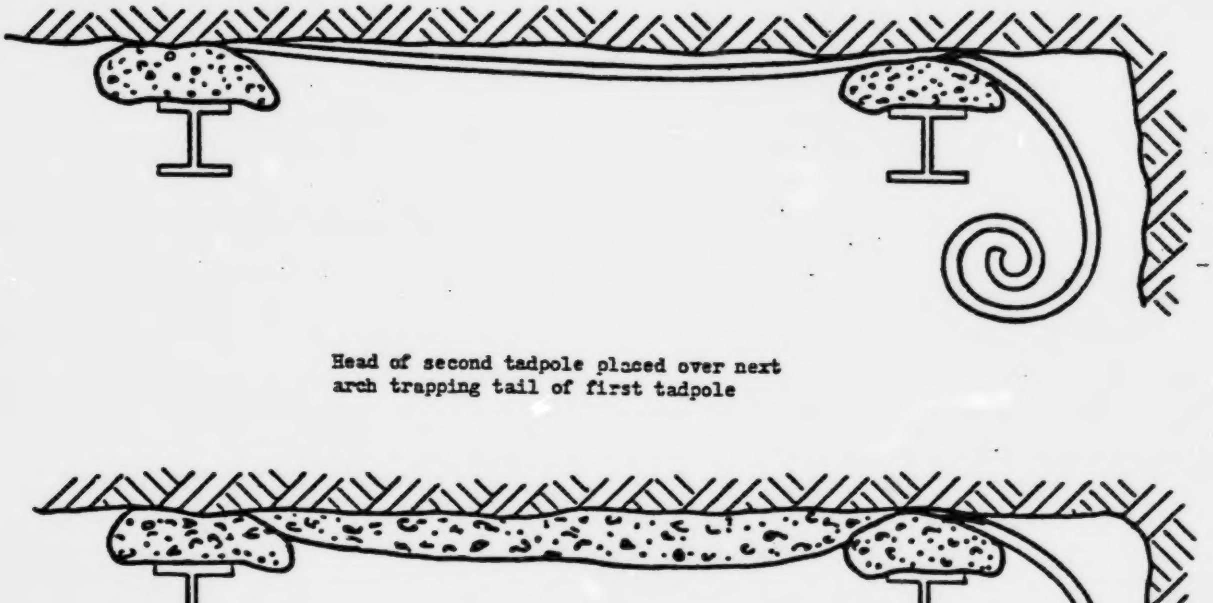


Section through tadpole bag

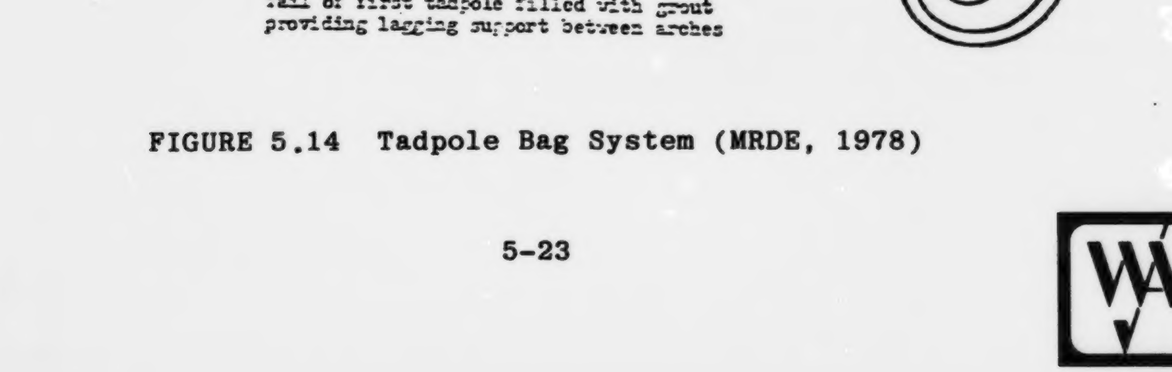
FIGURE 5.13 Tadpole Bag Grout Envelop (MRDE, 1978)



Head placed over arch and filled with grout - tail rolled up



Head of second tadpole placed over next arch trapping tail of first tadpole



Tail of first tadpole filled with grout providing lagging support between arches

FIGURE 5.14 Tadpole Bag System (MRDE, 1978)

lagging. Concrete sprayed surfaces cannot be exposed to excessive convergence, otherwise continuous and expensive repair work is necessary. Also, excessive convergence would create a loss of integrity of the cement based support shell due to induced tensile stresses against which conventional concrete sprays have limited stength.

As a roadway lining material, shotcrete has traditionally been applied in a multi-layer application as follows:

- inital spray of a consolidation layer 3 to 5 cm. in thickness of high early strength shotcrete. This thin layer serves two functions; it must be strong enough to restrain the high forces that will initially be transferred to it by the converging rock mass, and it must be flexible enough to withstand any initial convergence without fracturing. A range of special consolidation materials are available commercially;

- One or more thicker layers are sprayed and reinforced with steel mats or lattice beams. These thick layers constitute the bearing component of this lining system.

Shotcrete techniques include a dry or wet process which facilitate pneumatic or hydraulic transport of the concrete from the mix machine to the spray nozzle. The concrete spraying process that dominates the application of shotcrete in mining is the dry process using an open-system rotor machine with thin-stream pneumatic conveyance of the concrete mix to the spray nozzle. The water required for the mix is added at the nozzle (Felstkorn, 1985).

Significant problems have been identified with the use of steel mat and lattice beam reinforcement in shotcrete. These problems include the fact that the spraying process leaves voids in the shotcrete which would generate weak zones within the support shell. Also, vibrations in the reinforcement members created by the spray stream of concrete partially vitiate the good compaction of the shotcrete.

New Austrian Tunnelling Method

An alternative to the traditional shotcrete technique is provided by the New Austrian Tunnelling Method (NAT) (Albers, 1982), (Albers, 1985). This method comprises a thin consolidation shell and a thick single or multi-layer bearing component, much the same as the conventional shotcrete technique.

The major difference of this technique is the use of rock bolts which are set following the application of the consolidation shell. Steel mesh or lattice beams are used to reinforce the thick bearing component shell.

The NAT has been extensively used in civil engineering tunnelling work and has proven the concept of using the self-supporting strength of the strata to form a static support element. The NAT system offers the advantage that the rock bolts provide a relatively stiff support to the consolidation layer and therefore minimize convergence. Limited work has been successfully done in several large openings in coal measure rock using the NAT (Felstkorn, 1985). Additional work must be done to evaluate its merits as an alternative support technique for mine roadways.

Steel-Fiber Reinforced Shotcrete

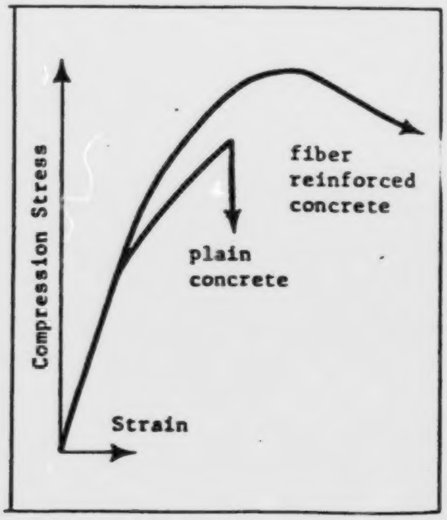
An alternative solution to the reinforcement problems experienced with traditional shotcrete methods is a concrete material with fiber reinforcement. The most common of these products is steel-fiber reinforced concrete. The addition of steel fibers to the shotcrete generates significant improvement in strength values over plain (non-reinforced) concrete as reported (Chironis, 1975) in Table 5.4. The fiber used by US Steel is marketed under the name "Fibercon Steel Fiber". It is produced from low carbon, full-hard or hard tempered (T-5 and T-6) flat rolled steel coils. The US Steel patent fiber configuration is .25 mm x .55 mm x 2.5 cm long. Its recommended usage is with a 1cm maximum size aggregate concrete or grout and in a concentration of between 0.1 percent to 8 percent of total concrete volume.

TABLE 5.4

(a) Improvement of Steel Fiber Reinforced Concrete over Plain (Non-reinforced) Concrete (Chironis, 1985)

Properties	Improvement over plain concrete
Compression	30%
Flexural modulus of rupture	200%
Tensile strength (direct and indirect)	200%
Impact strength and spall resistance	1,000%
Crack resistance	200%
Fatigue strength to 2-million cycles	50%
Abrasion	30%
Shear and torsional strength	300%
Corrosion resistance	Good as or better
Freeze-thaw	Good as or better

(b) Relative Stress vs. Strain Relationship for Plain and Steel Fiber Reinforced Concrete (Chironis, 1985)



Steel fibre reinforced shotcrete has been used extensively in U.S. room and pillar coal mines with great success (Chironis, 1975). It has also been tried in the German coal mining industry with success (Masson, 1985). Unlike the conventional shotcrete multi-layer system, steel-fiber reinforced shotcrete is applied in a single-shell. This system proposes using steel-fiber shotcrete to become a bearing construction of monolithic character and so attain a single-shell design (Felstkorn, 1985). Several problems have been documented (Masson, 1985) for this product, such as:

- the backsplash of a conventional dry mix shotcrete (15 - 20%) is greatly increased to 30 - 35% for the steel-fiber reinforced shotcrete;
- the proportion of steel fibers in the backsplash is disproportionately high;
- the steel fibers tend to generate a high rate of wear on the spray system (mix machine, hoses and nozzle).

Steel fiber shotcrete can be applied by either the dry or wet processes.

Precast Techniques

Two precast concrete lagging boards have been reported in the literature. Both of these products use OPC as the major component of the mix, but, due to the low tensile strength of plain concrete beams, modifications of the OPC beam structure was required. These modifications were achieved by:

- glass reinforced OPC lagging boards;
- saran-latex modified OPC lagging boards.

Glass Reinforced OPC Lagging Boards

Glass reinforced ordinary portland cement (GRC) technology was tested and reported (MRDE, 1978) by Pilkington Brothers Limited to determine its applicability as a material to be used in the manufacture of lagging boards. The fibres are zirconia-containing glasses, 25 mm in length, and are marketed by Pilkington under the name "Cem-Fil." Two methods are used to manufacture products of GRC which include:

- Premix technology

° poured into open moulds, slipform, or press mould;
° mass production using modified asbestos concrete products manufacturing facilities

- Spraytechnology

° manual spray into mould;
° mechanical spray in thin sheet onto a converyor belt.

A typical mix for glass reinforced cement is given in Table 5.5. The physical properties and design values for GRC are given in Table 5.6.

The work conducted for the MRDE consisted of trials on three products:

- cast, solid rectangular GRC boards;
- GRC sheets wet-bonded to perforated steel sheets formers followed by a 28 day cure in a humid atmosphere (fabricated by Charcon Composites Ltd.);
- moulded GRC piling sheets imported from the Netherlands.

The solid GRC boards demonstrated adequate strength; however, the costs were very high because of the large volume of GRC required. The composite steel sheet GRC lagging board performed poorly and trials were abandoned due to poor bonding of the composite lagging board. The piling sheet trials proved successful and based on this performance, three designs for GRC profiled lagging panels were proposed (but never manufactured for prototype testing).

- constant thickness profiled panel;
- profile panel with thick flanges;
- sandwich sheets (GRC shell filled with vermiculite or a similar inert compound).

TABLE 5.5 Composition of Glass Reinforced Concrete
(MRDE, 1978)

COMPONENT	QUANTITY
1. High Grade Silica Sand	20 - 30% by weight
2. Ordinary Portland Cement or Rapid Hardening Cement	
3. Cem-Fil AR Glass Fibres (25 mm long) *	< 5% by weight
4. Water	
5. Additives when required	

* 25 mm length fibers restrict radius of bends in GRC products to 12-15 mm to avoid fibers protruding from the matrix.

TABLE 5.6 Properties of Glass Reinforced Concrete (MRDE, 1978)

	Spray (Dewatered)	Spray (Non-Dewatered)	High Shear Premix	Standard Premix	Recommended Design Values	
					Normal Manufacturing (N/mm^2)	Asbestos Type Manufacturing Process (N/mm^2)
Density (t/m^3)	2.0-2.2	1.7-2.1	1.9-2.1	1.8-2.0	-	-
Impact Strength (N/mm^2)	15-30	10-25	10-16	8-14	-	-
Compressive Strength (N/mm^2)	60-100	50-80	-	-	6.0	-
Youngs Modulus (kN/mm^2)	16-25	10-20	16-22	13-18	-	-
Bending Tension (N/mm^2) Limit of Proportionality Moment of Rupture	 10-16 28-42	 7-11 21-31	 8-12 18-22	 7-9 14-18	6.0	5.0 (4.0)*
Direct Tension (N/mm^2) Limit of Proportionality Ultimate Tensile Strength	 7-9 10-17	 5-7 8-11	 - -	 - -	3.0	2.0
Strain to Failure (percentage)	0.7-1.3	0.6-1.2	-	-	-	-
Shear (N/mm^2) Interlaminar In-plane Punch Through	 2-3 8-11 35-50	 1.5-3.0 7-10 30-40	 - - -	 - - -	0.5	-

The design criteria established (MRDE, 1978) for each of these designs is given in Table 5.7.

Economic analysis by the MRDE of GRC lagging boards have shown that the costs are 60-100% higher than wooden or corrugated steel lagging systems. No further developments of this technology are reported by the MRDE although at the time of investigation (1978) it was anticipated that the cost and shortage of supply of wood lagging would necessitate the ultimate development of this product. It is commented by the investigators that the profiled sheets would create voids between the profiles which could represent a place around the roadway profile for methane to collect. To eliminate this problem, a foamed grout or some similar weak material could be injected behind the profiled GRC lagging boards. For this reason the MRDE indicated that lower costs would be achieved by the sandwich GRC board and promoted its development in favour of the profiled boards. Also, the sandwich board is simple to install while the profiled board was anticipated to present a problem in installation.

Saran Latex Modified OPC Lighweight Reinforced Concrete Lagging Board

Work conducted by the Dow Chemical Company, Midland, Michigan, under contract to the U.S. Bureau of Mines, produced a lagging board comprised of saran latex modified ordinary portland cement, lightweight aggregate, reinforced concrete lagging board, (Eash and Kirchner). The board was designed with a "T" section to minimize weight and reinforcement was used to improve the flexive and diagonal shear strength of the member. Lightweight aggregate was used to further reduce the weight of the lagging board. Details of this lagging board are given in Figure 5.15. The concrete mix composition and details of the lightweight aggregate blend used in the concrete are given in Tables 5.8 and 5.9 respectively.

Saran latex modified concrete was identified for this application because of the following properties:

TABLE 5.7 Design Criteria for GRC Profile Lagging Panels, Exhibiting the Same Strength as Wooden Lagging Boards

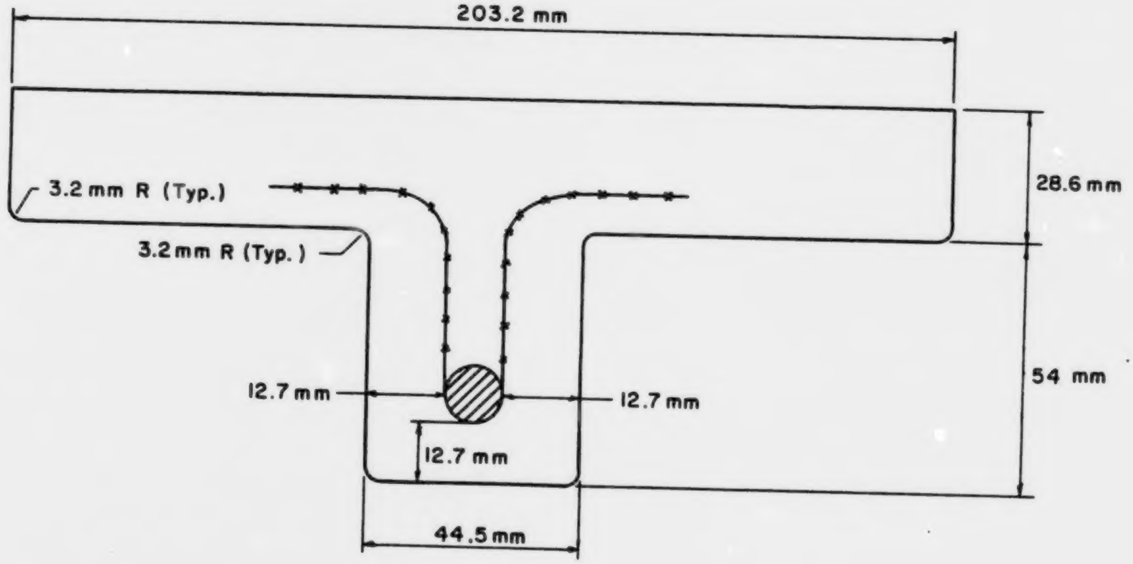
		MANUFACTURING PROCESS				
		SPRAYED METHOD (Standard GRC)		ASBESTOS CEMENT METHOD (Light-Weight GRC)		
		RECOMMENDED DESIGN		RECOMMENDED DESIGN		CONSERVATIVE DESIGN
DESIGN BASED ON STRESS MECHANISM		BENDING	DIRECT TENSION	BENDING	DIRECT TENSION	
SECTION MODULUS (x10,000 mm/300 mm width)		13.2	26.4	15.8	26.4	
Constant thickness profile						
	Width (mm)	590	600	590	600	610
	Depth (mm)	175	200	175	200	250
	Thickness (mm)	15	12	15	12	15
	Volume of GRC per meter of tunnel ($10^{-3}m^3$)	11.6	8.9	11.6	8.9	13.2
Profile with thick flanges						
	Width (mm)	600	600	600	600	600
	Depth (mm)	160	200	160	200	240
	Thickness (mm)	10	7	10	7	10
	Volume of GRC per meter of tunnel ($10^{-3}m^3$)	9.8	7.1	9.8	7.1	10.3
Sandwich Panel						
	Depth (mm)	155 105	95	155 105	95	180 135
	Thickness (mm)	6 10	12	6 10	12	8 12
	Volume of GRC per meter of tunnel ($10^{-3}m^3$)	5.3 7.7	8.9	5.3 7.7	8.9	7.4 9.9

- it has a compressive strength twice that of normal concrete;
- it has a tensile strength three times that of normal concrete;
- it has exceptional resistance to freeze thaw cycles (evidenced by its extensive use in resurfacing bridges in the Northern U.S.);
- it greatly improves the bond strength of the concrete to the reinforcing steel. Normal concrete has a pull-out strength to a No. 5 rebar of 2 to 6 MPa; the saran latex modified cement has a pull-out strenght of greater than 18.6 MPa;
- the modified concrete lagging board demonstrates good deflection characteristics due to the high bond strength of the concrete and reinforcing steel which would not be possible with a normal reinforced concrete memeber;
- cracking of the concrete during excess deflection of the modified concrete lagging board provides an early warning system of a high stress situation without the loss of integrity of the member. The boards do not demonstrate a catastrophic failure mechanism when stressed to failure.

It was concluded from analysis by Dow Chemical Company that use of saran latex modified OPC lagging boards versus wood, could not be justified for economic reasons. The 1980 analysis (Eash, et al., 1981) outlined unit costs of $2.89 for wood lagging and $7.20 for the modified concrete lagging board based on equal support area and service period. This study did not comprehend the reduced risk of fire provided by the new technology.

Mine trails for this new lagging board were evaluated at two U.S. mines (McLaughlin, et al., 1984).

° Bunker Hill Mine, Kellogg, Idaho (trail done with lagging board in a fault zone of a permanent drift - heavy ground reported).


203.2 mm
3.2 mm R (Typ.)
3.2 mm R (Typ.)
28.6 mm
54 mm
12.7 mm
12.7 mm
12.7 mm
44.5 mm

Reinforcing Rod:	No. 6, galvanized bar, Grade 60
Steel Mesh:	50.8 x 50.8 mm galvanized woven wire fabric (stirrups)
Length:	149.9 cm

FIGURE 5.15 Saran Latex Modified OPC, Lighweight Aggregate Reinforced Concrete Lagging Board (Eash, et al, 1981)

TABLE 5.8 Composition of Concrete Mix (Eash, et al., 1981)

Mix Proprotions:	Part by Weight
Portland Cement - Type III	94
Buffalo Haydite - Type FF	94
Buffalo Haydite - Type RT	47
Buffalo Haydite - Type A	47
Concrete Sand	94
Dow Latex 464 (50% solids)*	9.4
Dow Corning Antifoam B	0.19
Prewet Water	29
Mix Water	26

Average Properties:	
Wet Concrete Density	121 lb/ft^3
Air Content	3.3%
Compressive Strength	
7 day cure	5200 psi
28 day cure	6000 psi
Flexural Strength	
28 day cure	580 psi

TABLE 5.9 Buffalo Haydite, Lightweight Aggregate (Eash, et al., 1981)

Screen Analysis:

Sieve Size	Percent Passing		
	Type FF	Type RT	Type A
1/2"	100	100	100
3/8"	96	100	100
#4	7	83	100
#8	2	43	85
#16	1.9	23	67
#30	1.9	13	51
#50	1.8	8	24
#100	1.5	5	3
Bulk Density:	50.0 lbs/ft^3	58.2 lbs/ft^3	66 lbs/ft^3

- Magma Copper Company
  San Manuel Mine, Arizona
  (trial done in two locations:
  - a permanent drift;
  - in a very high stress grizzly level).

The Bunker Hill trials proved a successful application of the modified cement lagging boards. The application at Magma Copper was successful on the permanent drift; however, it failed under the very high stress levels in the grizzly level (which is traditionally supported by a reinforced concrete lining).

Trials with a prestressed saran latex modified cement lagging board, of a similar "T" section, were unsuccessful due to low strength tensile failure.

6.0 GATESIDE PACKWALL SUPPORTS

The application of gateside packwalls in longwall mining provides two functions (Whittaker, Woodrow, 1977):

1. Strata Control:

   - immediate strata control to protect gateroad supports while extracting the face;

   - to create a definitive break-off line at the waste edge of the gob;

2. Environmental control:

   - accommodate the disposal of dirt and debris from workings;

   - minimize air leakage across the gob.

A listing of the techniques which have been developed for gateside packwall construction is given in Table 6.1. The variability in the load bearing capacity for these pack systems is outlined in Figure 6.1. Due to the range of available pack strengths, it is imperative that the anticipated pack loads be determined prior to packwall design. This determination is done for short term loads based on the Detached Block Theory (Whittaker, Woodrow, 1977) and longterm loads by the Roof-Beam Tilt Approach (Smart, et.al., 1984). A diagram depicting the principle of each of these theories is given in Figure 6.2 and Figure 6.3 respectively. The principal of an efficient packwall is that it will provide:

- high early resistance to loads generated by the extraction of coal to minimize separation of the immediate roof strata while the gate-end face supports are in the region of the packwall. This support function is required until the face has advanced through 6 to 8 strips or represents about 24 hours of production (Smart, et al., 1982);

TABLE 6.1 Gateside Packwall Construction Methods

6.1 Stone packs (hand built)

6.2 Wooden packs

6.3 Composite packs
- open wood frame filled with debris/dirt
- alternating wood/concrete layers (sandwich packs)

6.4 Precast concrete blocks
- autoclaved aerated concrete blocks
- lightweight aggregated concrete blocks
- steel-fiber reinforced concrete block

6.5 Pneumatically placed packs
- complete backfilling of face
- strip side packwalls

Materials used:
- debris/dirt
- wash plant refuse
- *- natural anhydrite

6.6 Mechanically placed packs
- slusher packing
- blade packing
- ram packing

6.7 Hydromechanically placed packs:
- *- synthetic anhydrite based pack
- *- cemented debris/dirt packwall (pack consolidation)
- cement based packs.
  - * cement, water, accelerator (coal/stone slurry) (Thyssen, Warbret)
  - * cement, water, accelerator, bentonite (Tekpak, Astrapak, Aquapak, Aquablend)
  - * cement, water, flyash, (Al or Fe sulphate) (Flashpack)

* These systems comprise a family of packing systems which are referred to as Monolithic Packs.

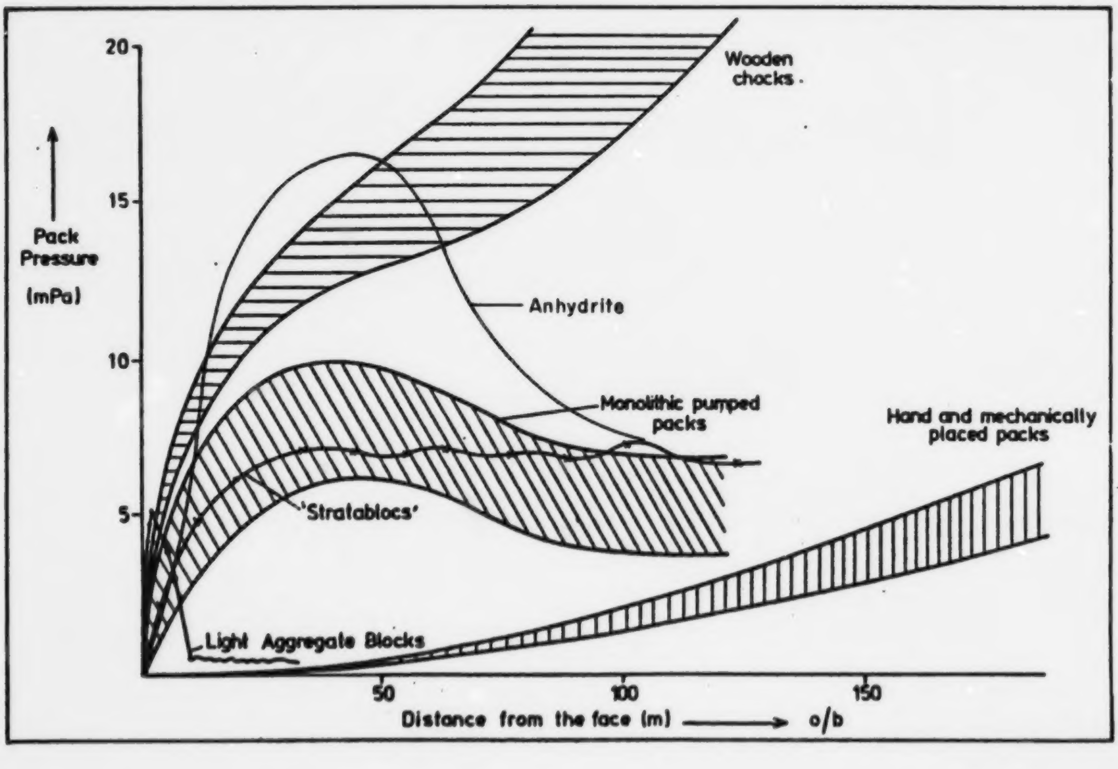


FIGURE 6.1 Diagramatic Relationship of Gateside Pack Load Characteristics (Whittaker, Woodrow, 1977) (Note: Anhydrite Curve) (Blades, Daves, 1974)

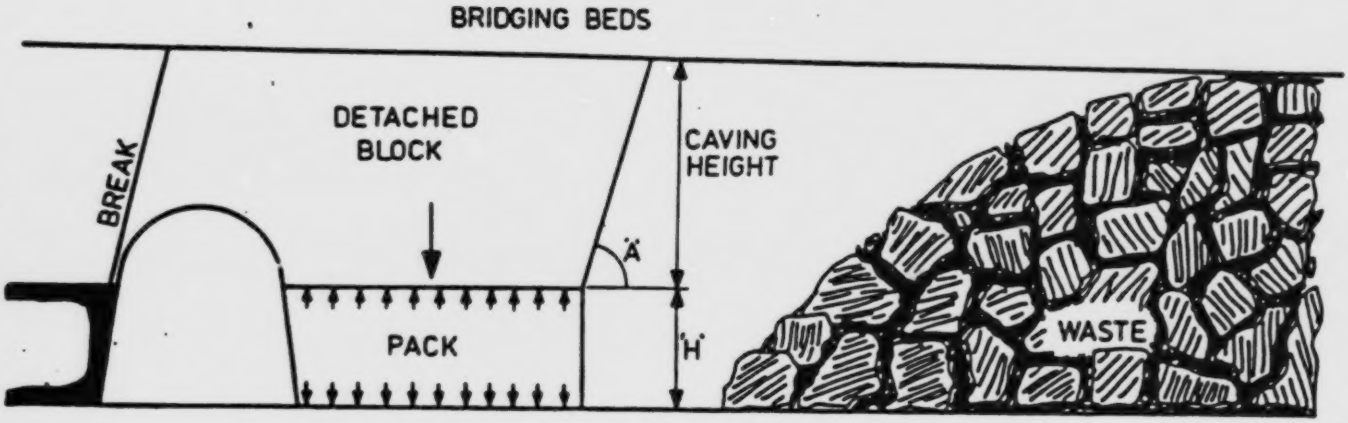

BRIDGING BEDS
DETACHED BLOCK
BREAK
CAVING HEIGHT
A
PACK
H
WASTE

FIGURE 6.2 Presentation of the Detached Block Theory for the Determination of Short-Term Pack Loads (Clark, Newson, 1985)

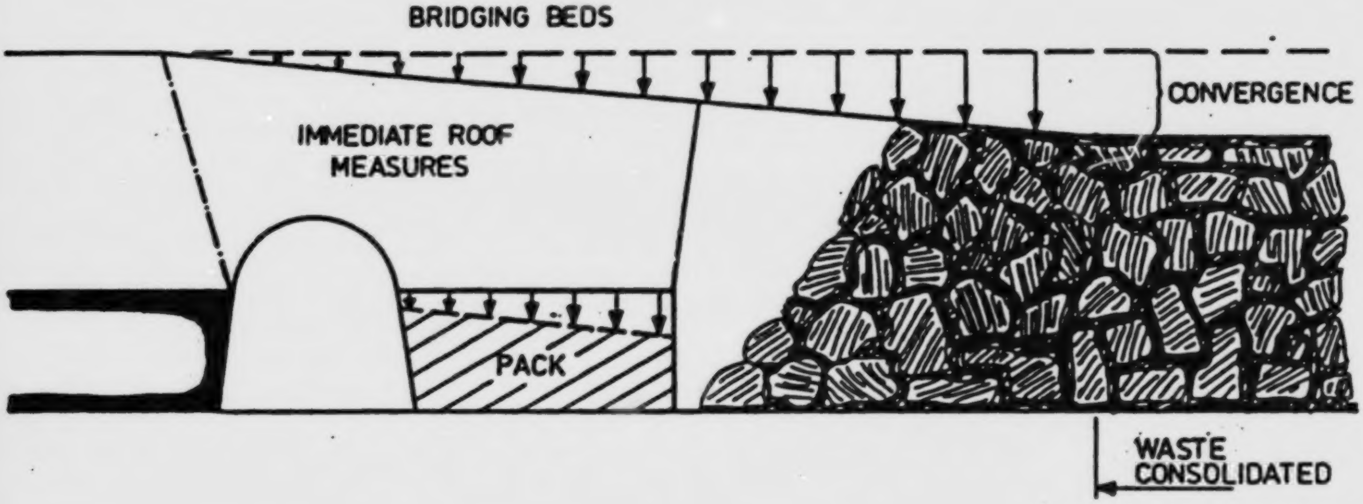

BRIDGING BEDS
CONVERGENCE
IMMEDIATE ROOF MEASURES
PACK
WASTE CONSOLIDATED

FIGURE 6.3 Presentation of the Roof-Tilt Theory for the Determination of Long Term Pack Loads (Clark, Newson, 1985)

- long term yield capacity that will assimilate the inevitable movement of the roof and floor stata which is controlled by the mined seam thickness, caving and compression characteristics of the waste material. This yielding property will allow the pack to shed the load created by the strata movement in a controlled manner, and limit the possibility of a roof failure or a floor punching problem that is possible with a long-term stiff pack material (Clark, Newson, 1985).

It is observed from the packwall systems outlined in Figure 6.1 that wooden chocks do provide an excellent high early strength but do not provide the required long term yield capacity. Hand and mechanically placed packs provide poor early strength characteristics. Lightweight aggregate concrete blocks demonstrate a very limited range of strength as a packwall material and can be used in very restricted applications. Both "Stratablocks" (autoclave aerated concrete block) and monolithic pumped packs show a high early strength with favourable long-term yield properties. Anhydrite packs have a very high early load acceptance with an excellent yield characteristic, which in fact parallels that of monolithic pump pack systems.

A brief description of each of the systems as outlined in Table 6.1 follows; however, emphasis will be placed on the monolithic pack systems due to the current high degree of interest on this subject by the NCB, CANMET and CBDC.

6.1 Hand Built Stone Packs

Hand built stone packs are of historical significance as a pack wall system, but are not used in modern longwall operations. The system comprises a skillfully laid stone wall of ripping-debris which is backed by finer-sized dirt created in development work.

A series of problems with stone packs make this method unsuitable in comparison with the more modern packwall systems to be discussed in this project. These problems include:

- only skilled stone layers could achieve a strong pack wall;

- the wall construction process was very slow and would not support the requirements of modern longwall operations;

- the stone wall had to support the entire early load of the overlying strata as the backfilled dirt required significant compaction before it could support strata pressures. This compaction would only be provided by large convergence of the roof strata and stone packwall which are contrary to good packwall design criteria.

The hand built stone packwall system is consequently eliminated from further consideration as a packwall construction alternative.

6.2 Wooden Packs

Wooden pack construction constitutes a practical packwall construction technique used in modern longwall mining operations. This system does have several disadvantages:

- it requires the delivery of large volumes of pre-cut timber to the gate-ends;
- the wooden packs form a continuous flame path along the gateroads and therefore constitute a significant fire hazard for the mine. Fire-retardant treatment processes can reduce this hazard but will not eliminate it;
- Figure 6.1 indicates the excellent early strength of the wooden pack (it can be preloaded by wedging it against the roof); however, the yield character- istics of wooden packs indicate that adequate stored energy can be generated in these packs which may result in sudden and violent stability problems (Smart et al., 1982);
- the usage of wooden packs has been eliminated in West German coal mines and greatly reduced in United Kingdom coal mines due to poor supply and high costs. This action has generated the development of alternate technologies for packwall meterials which are superior to wood.

6.3 Composite Packs

Dirt-filled wooden packs have been used to reduce the quantity of wood required to build a pack and to provide a convenient location to place ripping-debris. As a support component of the composite packs, the dirt requires extensive compaction before it can contribute support resistance to the roof strata. Tests reported (Whittaker and Woodrow, 1977) on the resistance provided by loose dirt during large scale compression tests, (Table 6.2), show that the dirt does not contribute to early strength due to the large differential resistances provided by the composite pack materials.

A second type of composite pack is the sandwich pack, which was developed in South Africa. The sandwich pack is comprised of alternating layers of wood and concrete, Figure 6.4, which provide improved stiffness and yield properties for the pack as opposed to a wood only pack (Ortlepp, 1978). Extensive investigations have been conducted by Rand Mines Limited on the constructional features of sandwich packs to develop an optimal design. The results of this work are presented in Figure 6.5.

A third composite pack design was investigated using steel mesh trays and also sleeves to restrain short pieces of timber to construct the pack (Lewis, 1978). Instability of this chock unit against twisting failure and low pack efficiency eliminated this unit as a viable alternative to the ordinary wooden chock.

6.4 Precast Concrete Blocks

Work conducted by the NCB in search of a chock support timber replacement material resulted in the application of two precast concrete block systems:

- reinforced autoclave aerated concrete blocks;
- reinforced lightweight aggregate concrete blocks.

Recent work conducted by the USBM has identified a third chock support timber replacement material which is currently being field tested in several U.S. coal and trona mines. This product is known as: steel-fiber reinforced concrete (SFC) blocks.

TABLE 6.2 Differential Strength Characteristics of Loose Fill Pack Material (mudstone ripping-debris) and a 15 x 15 cm Wood Chock (2 pieces 60cm long) (Whittaker and Woodrow, 1977)

	Resistance (kN/m^2)	
Yield %	Ripping-debris	Wood Chock
0	0	----
3 1/2 (yield strength wood)	---	2500
5	15	2670
10	50	3780
15	95	4700
20	170	5060
25	300	5170

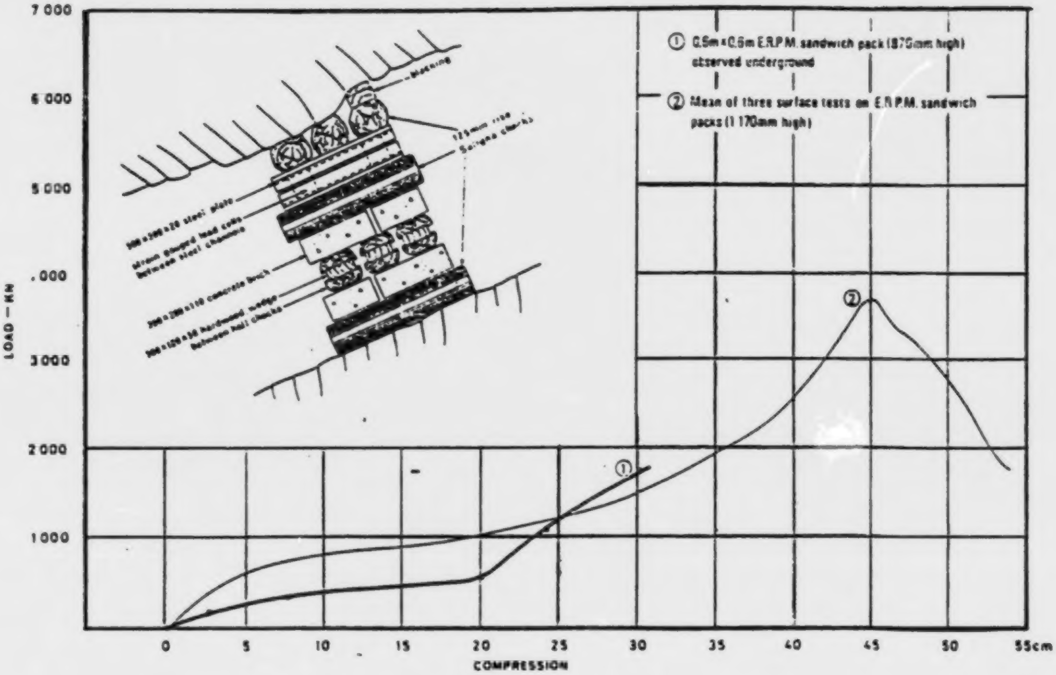


FIGURE 6.4 Comparison Between Laboratory-Determined and In-Situ Pack Characteristics (Ortlepp, 1978)

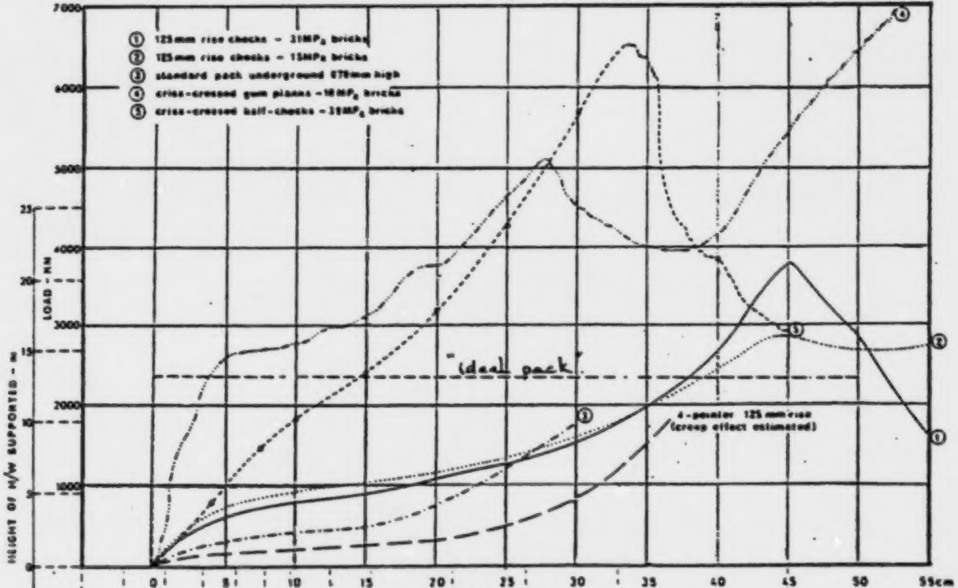


FIGURE 6.5 The Effect of Constructional Design on Pack Performance (Ortlepp, 1978)

Reinforced Autoclave Aerated Concrete Block

Cement and/or lime, pulverized metallurgical slag, fly-ash, sand or other siliceous fine aggregates are used as raw materials in the production of autoclave aerated concrete block. Hydrogen or air is introduced into a slurry composed of the raw materials to create a cellular structure. The slurry is cast in steel mould prepared with the necessary reinforcement. Curing of these castings is done under high pressure steam in an autoclave.

Constant atmospheric conditions, requirements for an autoclave, plus specialized mixing, curing and cutting equipment are required for this process. Consequently, autoclave aerated concrete blocks are prepared in specialized plants based on mass production of a standardized product, normally in the form of wall, floor and roof panels for commercial building construction (CEB Manual, 1978).

The application of reinforced autoclave aerated concrete block as a chock support member in several NCB coal mines was conducted using two products; Siporex Stratabloc and Celcon Block (Lewis, 1978). The major difference in these two products is that the Stratabloc has an internal wire mesh reinforcement and the Celcon Block uses external wire mesh sheets placed between the layers of the chock to provide reinforcement.

The stress/strain characteristic of autoclave aerated concrete blocks, Figure 6.1, demonstrates high early strength with an extended ductile yield zone followed by a non-violent crumbling failure with the block providing substantial post-failure support capacity (Lewis, 1978). The pack load characteristics of the Stratabloc is similar to that demonstrated by the monolithic pumped packs, Figure 6.1. Both products provide support requirements that sufficiently parallel wooden packs, as shown in Table 6.3, that their application as an alternative to wood in packs and chocks is accepted.

Lightweight Aggregate Concrete Block

The reinforced lightweight aggregate concrete block is comprised of sintered clay and shale aggregate concrete. This product is reported to have a very high early strength and a brittle, catastrophic failure mechanism after the yield point is reached (Lewis, 1978). The product demonstrates a poor post-failure support capacity. Reinforcement of these lightweight aggregate concrete blocks with wire-mesh leaf inserts between layers does not adequately restrain lateral deformation to make it an acceptable substitute material for wood in packs and chocks. The proprietary name of product tested by the NCB is Aglite blocks.

Research work, by the NCB (Lewis, 1978), indicated that external side restraint of the pack or chock would allow the lightweight aggregate concrete block to be stressed well beyond the (uniaxial) yield point; however, further development was not pursued.

Also, work was conducted on a foamed slag lightweight aggregate concrete block with internal polypropylene fiber reinforcement (Lewis, 1970). Tests on a prototype of this block showed it to be more suitable as a chock/pack member than the Aglite block; however, production problems and the anticipated high cost of the product prevented its commercial development.

Steel-Fiber-Reinforced Concrete Block

Preliminary work on steel-fiber-reinforced concrete blocks was initially reported by Lewis (1970), who investigated this block as an alternative to wood in chocks and packs. These NCB tests reported three detrimental properties of the steel-fiber-reinforced concrete block as an underground support member:

- catastrophic failure of the block at yield load;
- the blocks tested were heavy and difficult to handle;
- the steel fibers protruded through the wall of the block thereby necessitating the use of heavy leather gloves while handling the block.

TABLE 6.3 Load Capacity and Pack Performance of Wood and Autoclave Aerated Concrete Block Chocks (Lewis, 1978)

Material	Maximum Load (kn)	Performance Efficiency*
Hardwood	820	70
Softwood	360	73
Reinforced Stratablock	410	70
Reinforced Celcon Block	470	70

* Performance efficiency (Blight, 1978)

A co-operative research effort by the USBM and the Burrell Construction and Supply Company has led to the development of a steel-fiber-reinforced concrete block, which has been approved by the USBM, for use in the U.S. Coal Mining Industry (Byrd and Thompson, 1980). This block consists of a proprietary mix of cements, sand and aggregate, plus "bent-end" steel-fibers 0.50 mm diameter x 30 mm long with a 3 mm bent section at each end to prevent pullout. Extensive testing in the U.S. Department of Energy, Mine Roof Simulator (Byrd and Thompson, 1980) plus field testing has demonstrated the subject product, known as Fibrecrib Block, to have the following properties:

- a yield point much higher than wood (21MPa vs 4MPa) (Burrell Mining);
- a non-catastrophic compression failure at or near the yield point;
- excellent post-failure strength.

The product is available in two-standard block sizes which are produced on standard concrete block production machines with proprietary method modifications. To prevent roof or floor punching by the Fibrecrib block the roof and floor must be competent and have a compressive strength greater than 21 MPa (Burrell Mining).

Disadvantages of the Fibrecrib Block are reported as (Mason, 1982):

- the need to prepare a flat, smooth floor area for the base for the chock/crib to achieve proper support performance;
- the need to wear special protective gloves to prevent injury from the steel-fibers which protrude through the surface of the block.

The Fibrecrib Block has been successful in supporting high stress zones in US coal mines (retreat longwall and room and pillar) and trona mines where conventional support techniques; resin bolting, truss bolting, wooden crib/chocks, have failed (Smelser and Henton, 1983; Mason, 1982).

6.5 Pneumatically Placed Packs

In the West German longwall coal mines, pneumatic stowing is widely used in two (2) applications:

(1) to completely backfill the extracted seam the entire length of the face to limit the development of caving action over the longwall;

(2) to construct gateside strip packs in longwalls practising caving methods.

Complete Backfilling of the Face

The disposal of coal preparation washery tailings on the surface creates economic and environmental problems:

- potential pollution of ground water courses, which can be prevented only by costly preparatory work in the disposal area;
- pollution of the air;
- non-productive use of the land.

These problems can be reduced if the washery tailings are used to backfill the voids created by mining activities. The complete backfilling of a longwall face would be such an application.

The stowing material most commonly used, for complete backfilling of the face in West Germany, is coal washery tailings. Some operations practise mixing the tailings with mine waste material from a crushing plant. It is reported (Rauer, 1980) that cemented stowing materials have been successfully used in metal mines; however, due to the clay minerals in the washery tailings, cement is not an effective binder. High early strength of pneumatically stowed washery tailings has been achieved using admixtures of clayey small and ultra-small waste so that the stowing material has a low pore volume. The materials which have been used as admixtures include:

- flotation slurries from the coal washery plant;
- fly ash.

Research work is currently being conducted in the U.S.A. to investigate the technology of coal refuse backfilling systems (Bucek, 1980; Gaffney et al., 1982). The main impetus for this work is to reduce surface subsidence over longwall coal mine operations and to dispose of washery waste piles underground.

This work produced a cemented backfill using an aggregate mixture, by weight (Gaffney et al., 1981) of:

* Coarse Refuse (+ 28 mesh)	83 percent
Bottom Ash	4 percent
Fly Ash	10 percent
FGD Sludge	3 percent

* Preblended to design gradation.

The resulting cemented backfill exhibited the following strength values (Gaffney et al.; 1981):

	STRENGTHS (Mpa)		
% OPC	1 day	7 day	28 day
15 %	1.4	3.5	8.3
20%	8.7	13.8	18.6

It is commented that the cemented refuse backfill system was developed for application in Partial Room and Pillar mines or Auger Room and Pillar mines by either a hydraulic (viscous-plastic stowing) or pneumatic stowing. This system was considered "not applicable" to longwall or shortwall mining methods because of the low concrete strength development rate.

Within the content of this report, if wooden packwalls are maintained in future operations, an anticipated reduction of wood could be realized if a reduction in the size of the gateside packwall was possible. This size reduction may be achieved with the development of lower stress levels at the gateroads if complete back- filling of the face was implemented. Further geotechnical investigations are required to confirm the extent of this stress reduction and also the size of the reduced packwall structure.

Gateside Strip Packs

In the gateside strip packwall construction, natural anhydrite is pneumatically conveyed to the packhole where it is wetted and blown into place.

Natural anhydrite (calcium sulphate) when dampened, takes on water of hydration and forms interlocking gypsum crystals (hydrated calcium sulphate) which creates a hard crystalline material from the anhydrite particles.

A typical German Anhydrite product shows it to be a granular material with a general anhydrite flour matrix. The size of the largest granule does not exceed 7 mm and approximately 30% of the total weight is comprised of dust (Blades and Daws, 1974). This size distribution is necessary for several reasons.

- the material is transported pneumatically in pipes underground. Without large particles this would be difficult;
- the granules act in the reconstituted mass in a similar way to aggregate in concrete;
- a large part of the material must consist of dust particles to enable rapid action of the water upon the material to form a highly viscous mass.

The cementing property of natural anhydrite is used in the development of a cemented monolithic pack known as ANPAK. Coarse-grained natural anhydrite is pneumatically transported to the pack area where it is blown into a brattice or textile covered wire mesh lined packhole. At the outlet of the pneumatic stowing pipe, the anhydrite is spray-dampened with water and an accelerator (potassium/ferrous sulphate) solution to promote the cementing action of the anhydrite. The pack sets quickly, and after five hours has a compressive strength of 8 MPa (Cain, 1985). The ANPAK system has several negative characteristics:

- the pneumatic transportation of anhydrite creates very high abrasion of the pipe range which results in the use of expensive abrasion resistant pipe (pipe range limited to 1000 m to 10 cm diameter);

- despite the water/accelerator spray action at the packhole, the process is dusty;

- the system requires the importation of large volumes of anhydrite to the face area which represents high transportation and material costs.

A schematic diagram of the natural anhydrite packwall system is given in Figure 6.7.

It is reported (Blom and Rohrs, 1983) that R & D work has been done in West Germany on a mixture of 90 percent by weight natural anhydrite and 10 percent by weight fly ash for a pack material. Laboratory work has demonstrated the material has early and late strength properties the same as natural anhydrite. The advantage of 10 percent fly ash is a reduction in the material costs for anhydrite in the pack. Observations made during field tests of this material indicated:

- the material can be blown onto a near vertical slope which facilitates good pack placement work with no or limited lateral support in the gateroad;

- the material demonstrates good cohesion.

A 3 m wide by 3 m high gateside packwall and a center wall (to give a double entry) are pneumatically placed in the advance longwall operation of Mid-Continent Coal Mine, Co., USA, using a cementitious mixture of:

- -10 mm crushed Limestone aggregate;
- Product Cement (which is between Class I and III cements);
- 2 percent Calcium Chloride as an accelerator;
- water; spray damped at the nozzle of the pneumatic stowing pipe.

It is reported that some problems do exist with this system:

- the material is very stiff and tends to prevent longterm deflection of the strata as necessitated by good packwall materials (tested at 21 MPa after 2 days);

- the packs demonstrated some spalling action;
- the mix has a poor consistency owing to the high percentage of fines in the crushed limestone.

At the present time, work is being conducted on several improvements for this material:

- design for a screening facility to eliminate fines in the aggregate;
- steel fibre (50 mm) reinforcement is being tested (36 kg/m^3) to eliminate the spalling problem.

At the present time, this material is pneumatically transported and stowed by a Breiden Pneumatic Stowing machine. Transport distances of longer than 3100 m have been accomplished at Mid-Continent for the subject mixture.

An excellent report on state-of-the-art pneumatic stowing practices is done by Rauer (1983).

6.6 Mechanically Placed Packs

A variety of mechanical packing systems have been developed to place a gateside packwall using gateroad development waste material. These systems were developed to mechanize the gate-end activities; however, their application also replaced the use of wood for packwall construction.

The systems which have been developed in the U.K. are of three types (Carr and Kitching, 1977):

- slusher packers;
- blade packers;
- ram (cam) packers.

Slusher Packers

The slusher packer system consists of a slusher (bucket) which is drawn through the pack hole by two ropes attached to a double-drum winch (haulage unit). The haulage unit is located in the gateroad and an end pulley is attached to an anchor unit located at the gob edge of the pack. The anchor unit can be as simple as a prop or as elaborate as a powered support. Gateroad development waste is dragged by the haulage unit into the pack hole and rammed into the debris pile that forms the pack.

The system is quite efficient in the disposal of dirt; however, it is difficult to generate sufficient compaction within the dirt pack to provide the "initial strength" or the "developed strength" demanded for an efficient pack (Carr and Kitching, 1978(a)).

Blade Packers

There are three systems of Blade Packers:

- Webster Blade Packer
- Becorit Plough Blade Packer
- Joy Continuous Packer

Each of these systems uses a blade to transport the dirt into the packhole from the gateroad and to form the pack. The units are not able to place the pack material tight to the roof and therefore the degree of compaction achieved is limited (Carr and Kitching, 1978(a)).

The three systems have a unique method of working, outlined as follows:

Webster Packer

- the packer blade is dragged through the packhole by a chain haulage system;
- dirt is placed on the floor;
- the pack is put on from the face end out to the gateroad.

Becorit Plough Blade Packer

- the blade rides on a rigid guide rail attached directly to the powered supports and is hauled along the packhole by an endless chain haulage;
- dirt is placed on a ripping platform;
- the blade pushes the dirt from the ripping platform into the pack.

Joy Continuous Packer

- the dirt is conveyed the length of the packhole by a belt conveyor;
- the plough (blade) runs on slides over the conveyor and moves the dirt from the conveyor into the pack;
- a packing ram subsequently compacts the packed dirt;
- the unit puts the pack on from the gateroad into the waste edge of the packhole.

Ram Packers

There are two types of ram packers; the cam packers and the packing table. Both of these systems are capable of placing a well compacted pack; however, the packing table generates the best placed pack of all the mechanized packing systems (Carr and Kitching, 1978(b)).

Cam Packers

The cam packer consists of a series of cam boxes attached to the gob side of the powered face support. Each cam box is equipped with a gate (cam) which is pivoted on a vertical axis and is swung by a hydraulic piston through a 90° angle. This cam motion is used to convey the dirt along the packhole by alternate cam motion and finally into a tightly compacted pack. The mounting height of the cam boxes depends on the seam thickness, with typical locations on a rear canopy for thick seams and on the floor plate for thin seams. Both Gullick Dobson and Dowty manufacture Cam Packers.

Packing Table

The Dowty Packing Table consists of a platform which is maintainted at the gate end of the wall. The platform consists of a trough, used to collect the dirt as it is liberated (machine-cut or shotfired), and two "drawers", an upper and a lower. The dirt collected in the trough falls onto the upper drawer where a hydraulic ram pushes it into the packhole.

As the dirt rises to the level of the bottom drawer it, through its longer stroke, pushes the dirt to the back of the packhole. The maximum length of pack is 5 meters. This unit generates a well consolidated pack.

General Comments of Mechanical Pack Systems

The slusher packing system was the most frequently used mechanized packing system in the UK in the early 1970's. At this time, and because of alternative improved mechanical pack systems as well as the monolithic pack systems, its application has diminished quite rapidly because of improved pack performance achieved with alternative systems.

The blade packing system has maintained a steady usage in the UK while the Ram Packing System has enjoyed some increased usage. It would appear from the information available, that the overall usage of mechanized packing systems is constant.

6.7 Hydromechanically Placed Packs

The term monolithic packs is used to describe a group of packwall systems where the packwall material forms a cemented "rock-like" mass. This family of packwall systems can be segregated based on the placement technique (pneumatic or hydromechanical) and the binding agent (anhydrite or cement) used. An outline of these systems is given in Figure 6.6.

Synthetic Anhydrite Packs

Synthetic anhydrite is a by-product from the industrial production of hydrofluoric acid and phosphate fertilizers. It has the same chemical composition and demonstrates the same hydration processes as natural anhydrite; however, the synthetic type is much finer grained, Table 6.4. Due to the fine grained synthetic material, a potential dust problem would result if pneumatic placement tecniques were used. Consequently, the synthetic anhydrite is mixed with water (27%) and a hardener/accelerator at a mixing station and then hydromechanically transported and placed in the packhole.

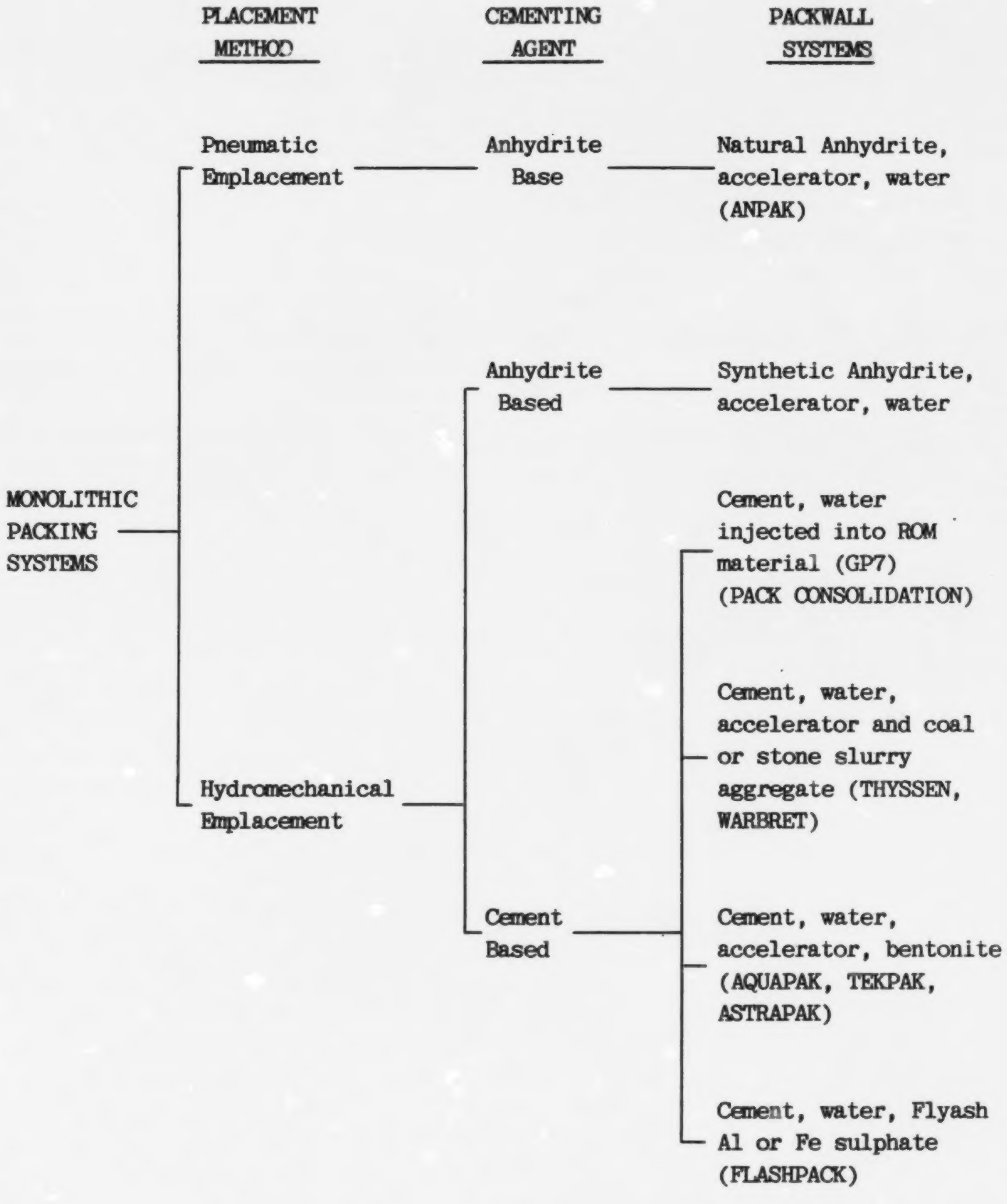

PLACEMENT METHOD
CEMENTING AGENT
PACKWALL SYSTEMS
MONOLITHIC PACKING SYSTEMS
Pneumatic Emplacement
Hydromechanical Emplacement
Anhydrite Base
Anhydrite Based
Cement Based
Natural Anhydrite, accelerator, water (ANPAK)
Synthetic Anhydrite, accelerator, water
Cement, water injected into ROM material (GP7) (PACK CONSOLIDATION)
Cement, water, accelerator and coal or stone slurry aggregate (THYSSEN, WARBRET)
Cement, water, accelerator, bentonite (AQUAPAK, TEKPAK, ASTRAPAK)
Cement, water, Flyash Al or Fe sulphate (FLASHPACK)

FIGURE 6.6 Outline of Monolithic Packwell Systems (after Cain, 1985)

TABLE 6.4 Grain Size Distribution of Natural and Synthetic Anhydrite as Used in Monolithic Pack Systems (Cain, 1985)

	Grain Size (% by weight)			
Type	>0.5cm	0.2 - 0.5cm	0.1 - 0.2cm	<0.1cm
Synthetic	4	15	23	58
Natural	70	10	4	16

The use of a slurry necessitates that the packhole be water tight to avoid excessive water in the gateroad. This requirement is provided by either of the following methods:

- use of a water-proof bag to line the packhole;
- construction of a packwall of dirt-filled bags tight to the roof.

Both of these watertight packhole construction techniques use filler pipes and breather tubes to accommodate efficient filling of the packhole with the pumped anhydrite material. A schematic of this system is shown in Figure 6.8.

Pack Consolidation Technique

A pack which is constructed of ROM material contains voids whether it was placed pneumatically or mechanically. The conversion of an unconsolidated ROM packwall to a monolithic packwall is accomplished by the injection of a highly permeable grout material. An example of a grout material for the secondary confinement of a packwall is the proprietary cement GP7, produced by Pozament Cement Limited.

Thyssen System

The Thyssen System was the first cement based monolithic pump pack system used in the U.K. in 1973. The Thyssen System comprises two separate slurries which are splash-mixed in the packhole. The composition of the two slurries is as follows:

Slurry 1 - Coal Slurry: ROM coal (-25 mm) + bentonite (Flowmat) + water
Slurry 2 - Cement Slurry: Cement (Packbind) + water

The coal slurry is pumped through a 100 mm diameter pipe from the outby mixing station to the packhole. Experimental work by the NCB has demonstrated that a maximum pumping distance of 2000 m can be accommodated; however, frequent blockage of the coal pipe range occured at this distance (McCathy and Robinson, 1981).

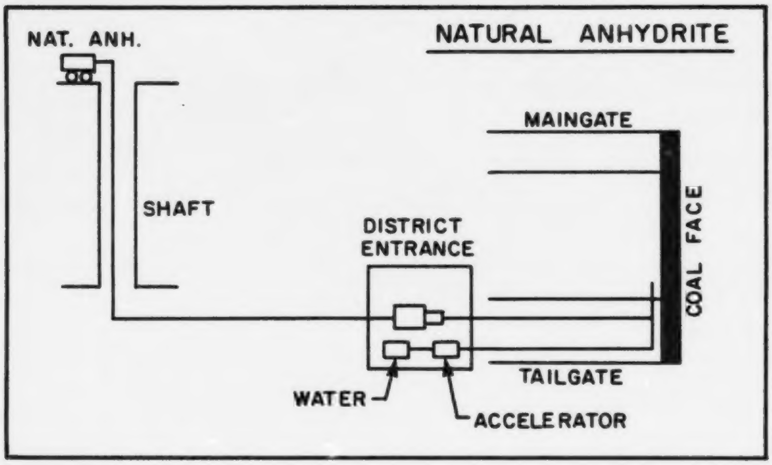

NAT. ANH.
NATURAL ANHYDRITE
MAINGATE
SHAFT
DISTRICT ENTRANCE
COAL FACE
TAILGATE
WATER
ACCELERATOR

FIGURE 6.7 Natural Anhydrite Packwall System

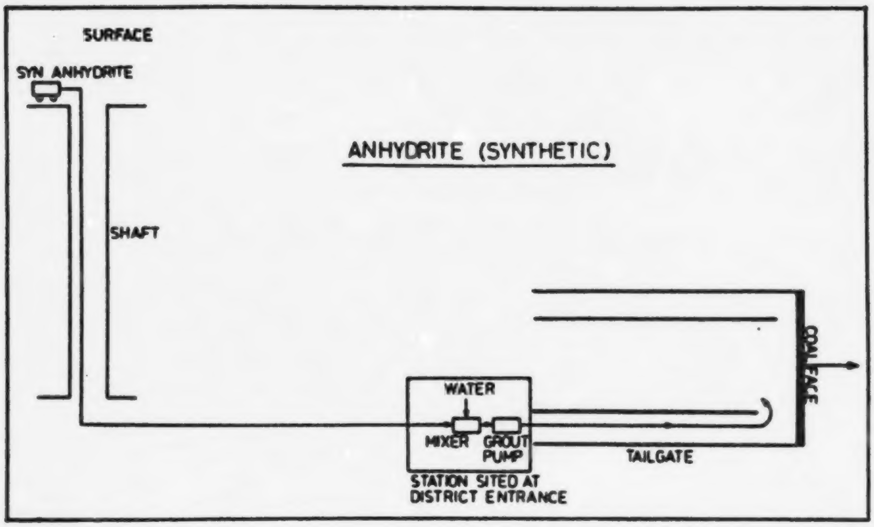

SURFACE
SYN ANHYDRITE
ANHYDRITE (SYNTHETIC)
SHAFT
WATER
MIXER
GROUT PUMP
STATION SITED AT DISTRICT ENTRANCE
TAILGATE
COAL FACE

FIGURE 6.8 Synthetic Anhydrite Packwall System (Clark and Newson, 1985)

The cement slurry is mixed separately and the pumping distance is restricted to 300 m due to the quick setting Packbind cement. The slurry mixture in the packhole must be contained by a water-tight structure. Two techniques were developed for this purpose:

- an L-shaped steel packhole shutter attached to the armoured face conveyor by two hydraulic rams, Figure 6.9 which can be independently advanced following the cement set time. To accommodate this technique, a special face-end support configuration is required (McCarthy and Robinson, 1981), Figure 6.10, consisting of:
  - ° two, 4-leg packhole supports each with two extending rear cantilevers and a hinged rear cantilever to provide immediate support in the packhole area;
  - ° two, 4-leg chocks with a 4-leg standard chock behind to control the angle of the waste cave from the side of the packhole to the regular face supports. The unit nearest the packhole has a long cantilever blade to support the waste on the side of the packhole. The second of these units has a much shorter extension in the form of a roof canopy that will provide an effective angled-breakoff line;
  - ° one, 6-leg buttress chock next to the regular face support.
- a pump packing bag constructed by sewing sections of brattice cloth, Figure 6.11. This pack bag requires limited confinement while the cement is setting. The confinement is often supplied by wire mesh panels and a simple framework of Dowty props and spars, Figures 6.12, 6.13 and 6.14. This framework is removed for reuse after the cement sets.

The major disadvantage with the Thyssen System is the loss of ROM coal used as the aggregate and the frequent plugging of the coal pipe range. A schematic diagram of the Thyssen System is given in Figure 6.15. Work has been conducted by

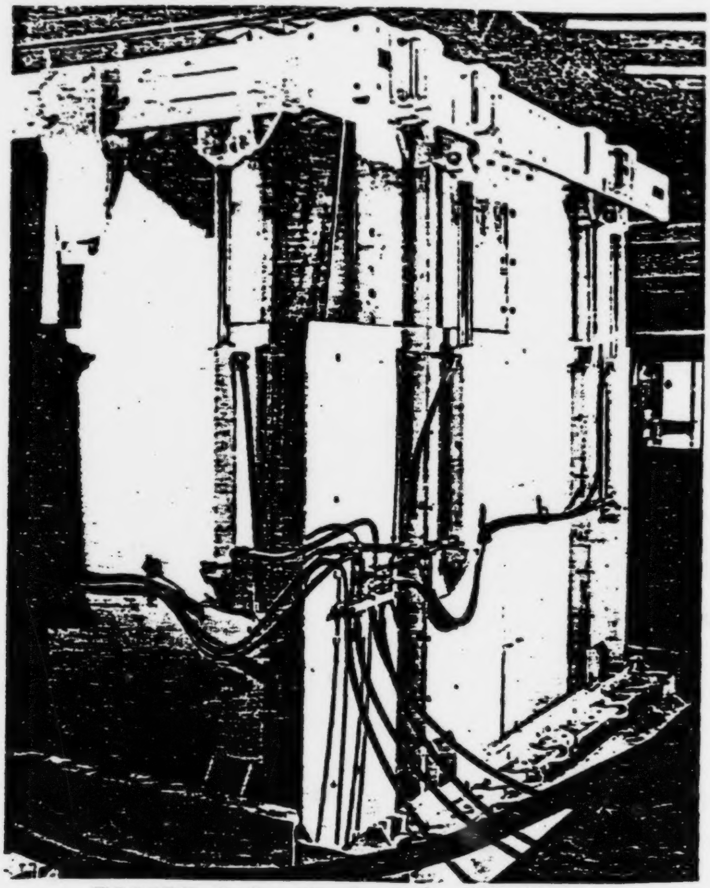


FIGURE 6.9 Pack Hole Shutter
(McCarthy and Robinson, 1981)

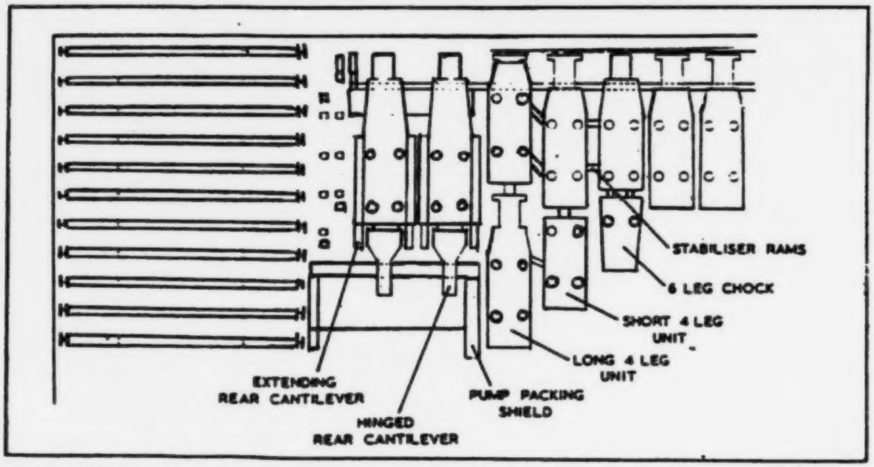

STABILISER RAMS
6 LEG CHOCK
SHORT 4 LEG UNIT
LONG 4 LEG UNIT
EXTENDING REAR CANTILEVER
PUMP PACKING SHIELD
HINGED REAR CANTILEVER

FIGURE 6.10 Layout of Packhole Support System
for Thyssen System
Using the L-Shaped Packhole Shutter
(McCarthy and Robinson, 1981)

the MRDE to replace the ROM coal with development waste (Cain, 1985). Also, a premixed bentonite/water pumping agent has been investigated to accommodate the pumping of waste from the surface for the Thyssen System (Cain, 1985).

Warbret System

Several of the operating problems of the Thyssen System were resolved with the development of the Warbret System. The quick setting, expensive "Packbind" cement was replaced by less expensive OPC. The quick set-time required for a cementaceous pack material was achieved in OPC by adding a NCB formulated accelerator, T.E.A.51. This accelerator does not react with bentonite, as do most commercially available accelerators, and could therefore be added to the aggregate slurry, not the cement slurry. This development allowed a much longer cement grout pipe range than was possible with the Thyssen System. Also, research work by the MRDE developed the technology to pump shales and washed dirt from the surface, for aggregate with the Warbret System (MRDE, 1981; MRDE, 1982).

Both the Thyssen and Warbret Systems require the delivery of either ROM coal or development waste to the pack site. This delivery constitutes a major problem with both systems due to variability in supply of aggregate for the underground mix plant/pump station (McCarthy and Robinson, 1981). One alternative to the insecurity of supply is to establish an underground storage bunker for the aggregate material.

Aquapak System

In an effort to eliminate the requirements for an aggregate in the pump pack (to simplify the pump packing operations and to eliminate the expense of the aggregate storage/supply) the MRDE developed a high water ratio cement. The cement, known as Aquacem (original name, Monopack), consists of three cementitious materials (the major component is OPC) plus admixtures to control the set time (Nixon and Mills, 1981). The addition of sodium carbonate, hardening agent, to this cement will generate both high early and late strengths.

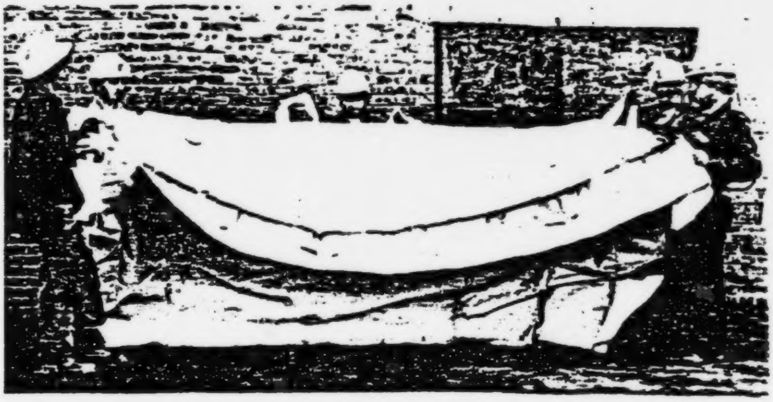


FIGURE 6.11 Pump Packing Bag Used to Contain Hydraulically Placed Pack Material (McCarthy & Robinson, 1981)

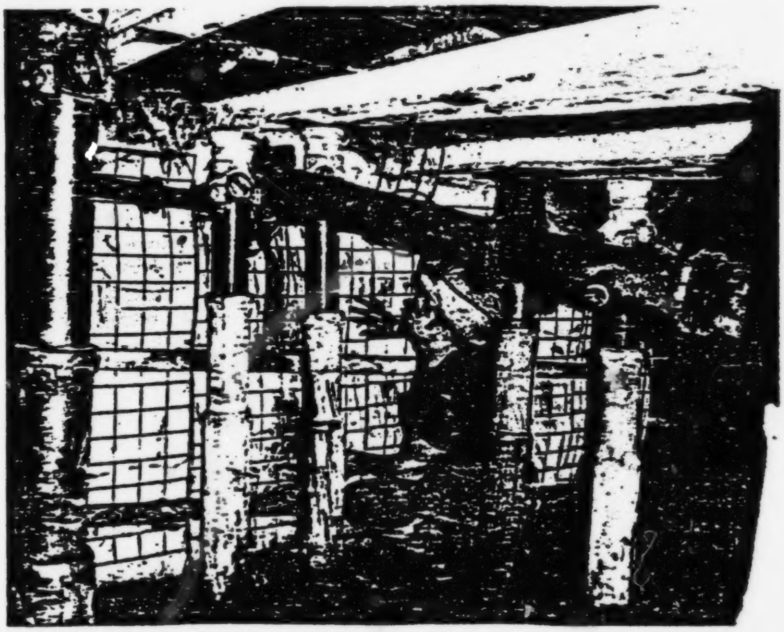


FIGURE 6.12 Pumped Pack Completed Into Bag (McCarthy & Robinson, 1981)

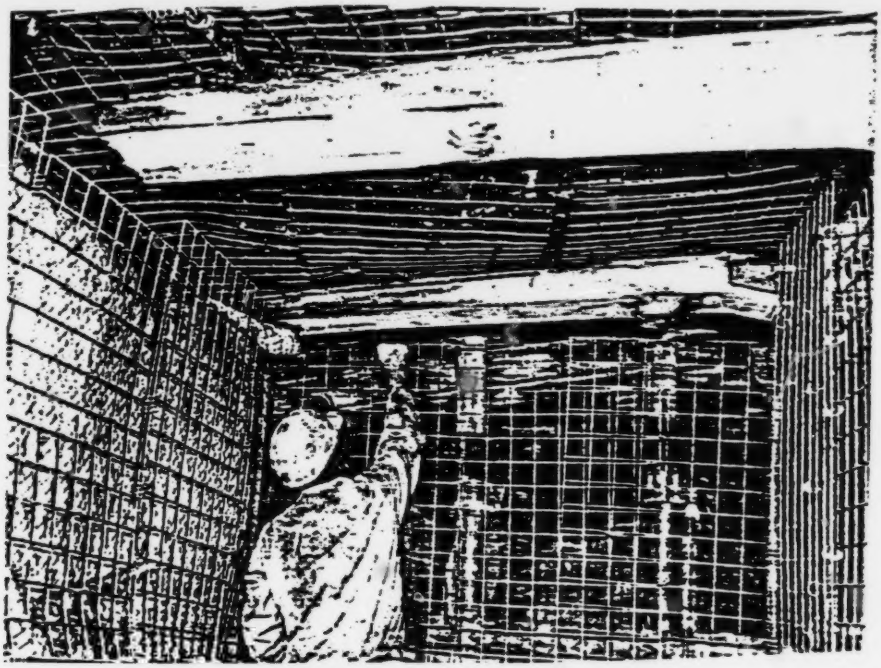


FIGURE 6.13 Mesh-Containing Cage Prior to Hanging Pump Packing Bag (Nixon and Mills, 1981)

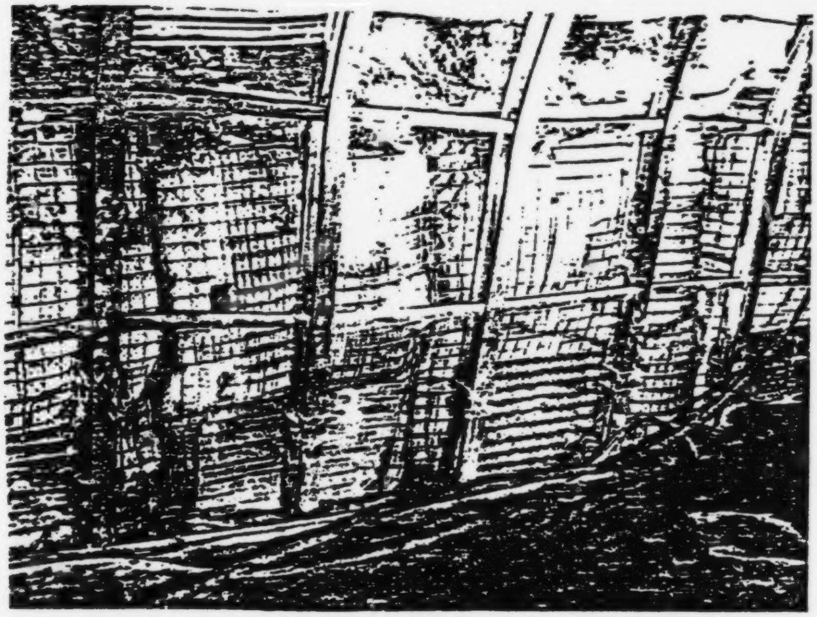


FIGURE 6.14 Return Gate Roadside with Pumped Pack Wall (Nixon and Mills, 1981)

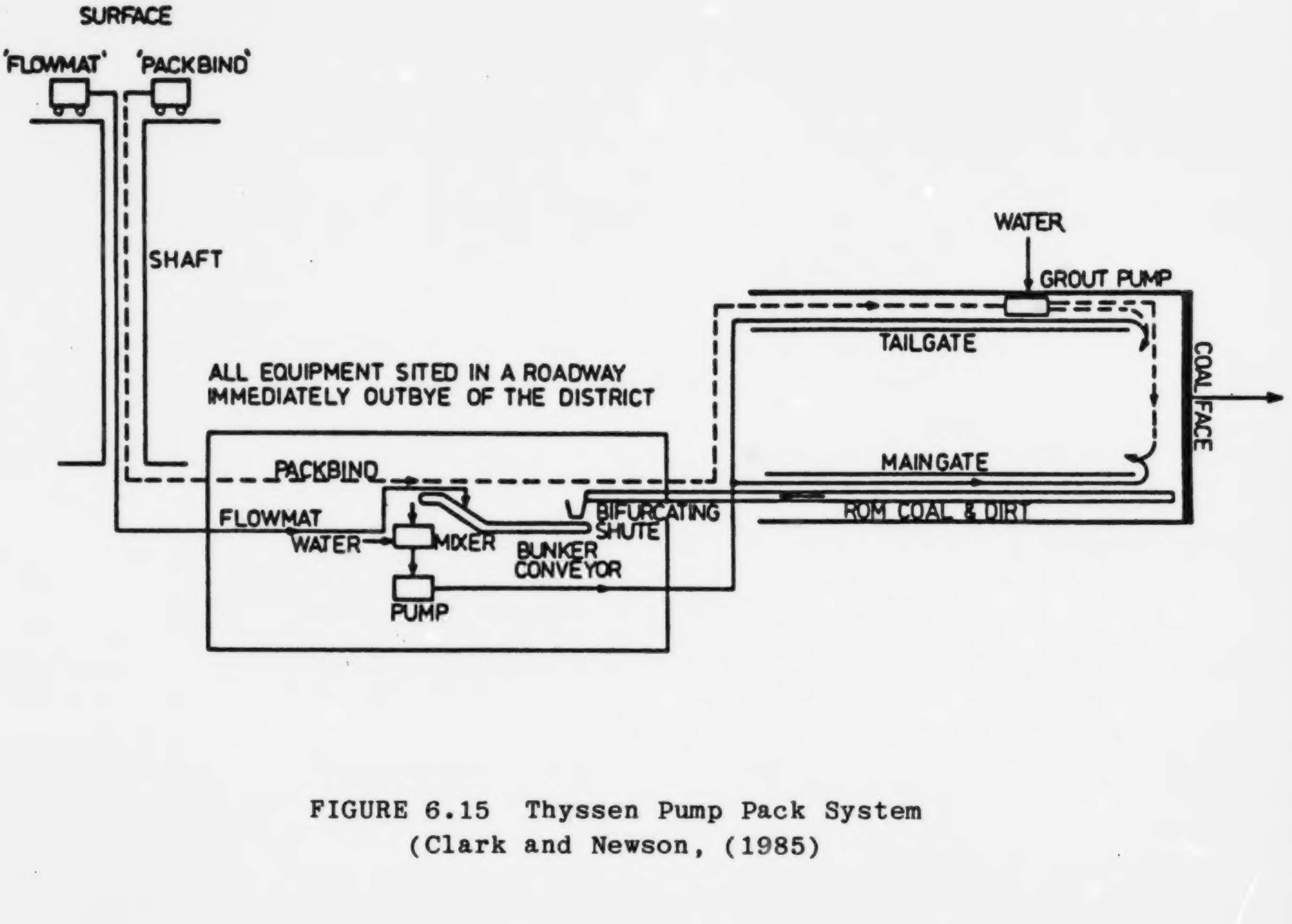

SURFACE
'FLOWMAT'
'PACKBIND'
SHAFT
ALL EQUIPMENT SITED IN A ROADWAY IMMEDIATELY OUTBYE OF THE DISTRICT
PACKBIND
FLOWMAT
WATER
MIXER
PUMP
BUNKER CONVEYOR
BIFURCATING SHUTE
WATER
GROUT PUMP
TAILGATE
MAINGATE
ROM COAL & DIRT
COAL FACE

FIGURE 6.15 Thyssen Pump Pack System (Clark and Newson, (1985)

The Aquapack system comprises the following two slurry mixtures to produce 1 m^3 of pack material:

- 360 liters of water + 450 kg Aquacem
- 500 liters of water + 50 kg Aquabent (1:1 ratio, bentonite + soda ash)

The Aquabent slurry does not set-up and therefore has an indefinite pumping distance reported as 3000 m (Smart et al., 1980). The Aquacem, however, sets rapidly and as a result must be mixed at a station with a maximum pipe range distance of 750 m (Smart et al, 1980). Because of this difference in the two slurries, the mix and pump station for the Aquacem is maintained outbye and Aquabent station is located inbye as outlined in Figure 6.16. The individual slurries are pumped through 25 mm hoses to the packhole where a cement mixture with 85 percent water is formed.

A pack bag is used to contain the mixed slurries for the minimum 20 minutes required for the mixture to set. The pack bag is restrained by a wire mesh frame which is hydraulically or manually advanced when the cement pack is set (usually in several hours).

In an effort to eliminate the separate Aquacem and Aquabent mix/pump stations, Posament Cement Ltd. has produced a blended Aquacem and Aquabent powder and has marketed this product under the name Aquablend. The major restriction of this blended cement/accelerator/pumping agent is that the maximum pipe range length is 250 m (Pozament Cement Ltd.).

Astrapak System (Tekpak)

The Astrapack System was developed to improve on the performance that was available with Aquapak. The major change with this system is the long range pumping capacity of the cement slurry. A refined hydraulic cement material was developed by the MRDE which extended the cement pumping life from the 45 minutes for Aquacem (in the Aquapak System) to 3 or 4 hours. The new product is marketed by Pozament Cement Ltd. under the name Astracem. The Astrapak System comprises the following slurry mixtures to produce 1 m^3 of pack material (Clark and Newson, 1985).

- 438 liters water + 175 kg Astrabent (bentonite + soda ash);
- 438 liters water +175 kg Astracem

The resultant mixture is 92% water in the packhole.

The extended pumping life for the cement slurry of the Astrapak System permits the combination of both pumping stations at a distance up to 1200 m from the packhole. Two 25 mm hoses are used to transport the slurries to the packhole where they are splash mixed in a frame supported pack bag, the same as described for the Aquapak System. A schematic diagram of this system is given in Figure 6.17.

Pozament Cement Ltd. reports an improved high early strength but the same long term strength for Astrapak and Aquapak/Aquablend.

Texpak is a competitive proprietary product which has the same application and formation as Astrapak. It is similarly comprised of two slurries, Tekcem and Tekbent, so named to retain commonality with the Astrapak and Aquapak systems.

Flashpack System

The basis of the Flashpack System is that special inorganic flocculants (aluminum sulphate and ferrous sulphate) react very rapidly with the hydration products of OPC to cause an instantaneous gelling action for the cement. This action is accomplished in the Flashpack system by using a two component system:

- OPC + water (4:6);
- Flyash, water, flocculant, bentonite (10:4:1:1)

These sluries are combined in a mixing gun at the packhole. The resultant mixture gels almost instantaneously and therefore eliminates the need for the pack bag required in other monolithic packing systems (Clark and Newson, 1985; Mills, 1984; Wood, 1983). The use of fly ash as a pozzolanic substitute for OPC generates a further advantage of replacing an expensive component (OPC) with an inexpensive, industrial process by-product (flyash).

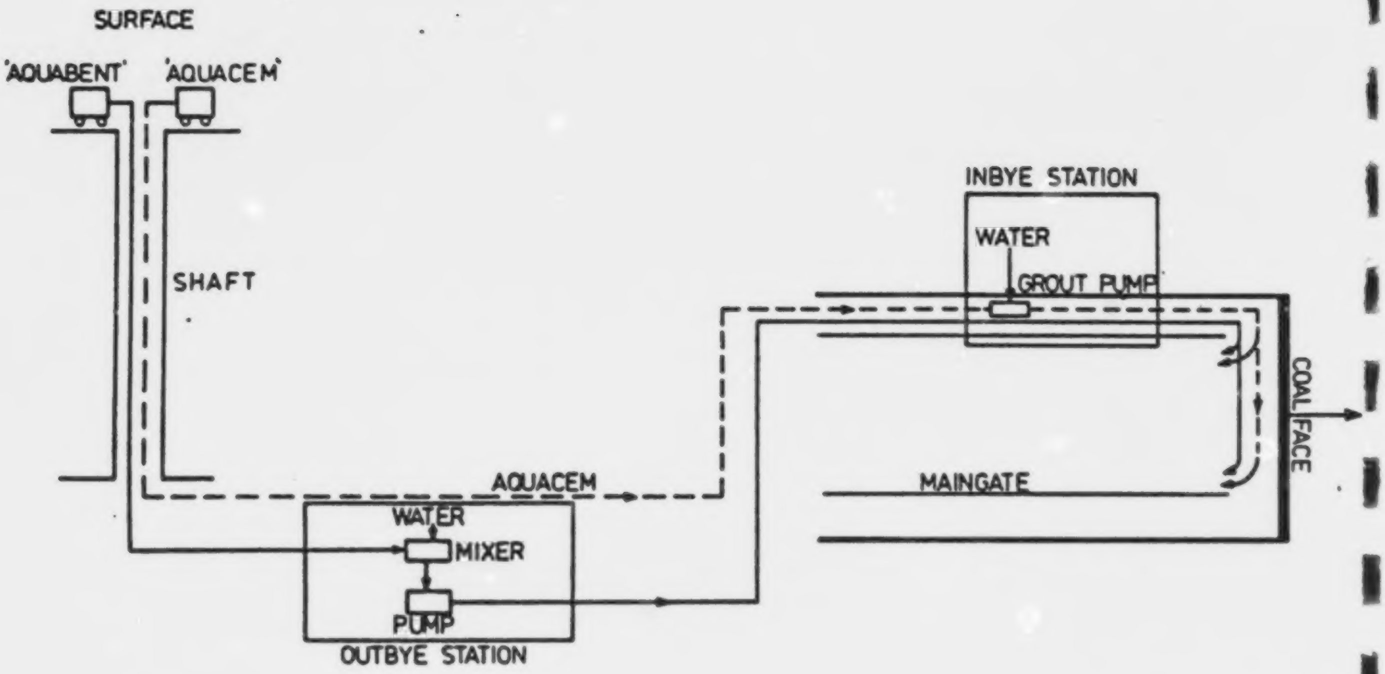

SURFACE
'AQUABENT'
'AQUACEM'
SHAFT
AQUACEM
WATER
MIXER
PUMP
OUTBYE STATION
INBYE STATION
WATER
GROUT PUMP
MAINGATE
COAL FACE

FIGURE 6.16 Aquapak Pump Pack System (Clark & Newson, 1985)

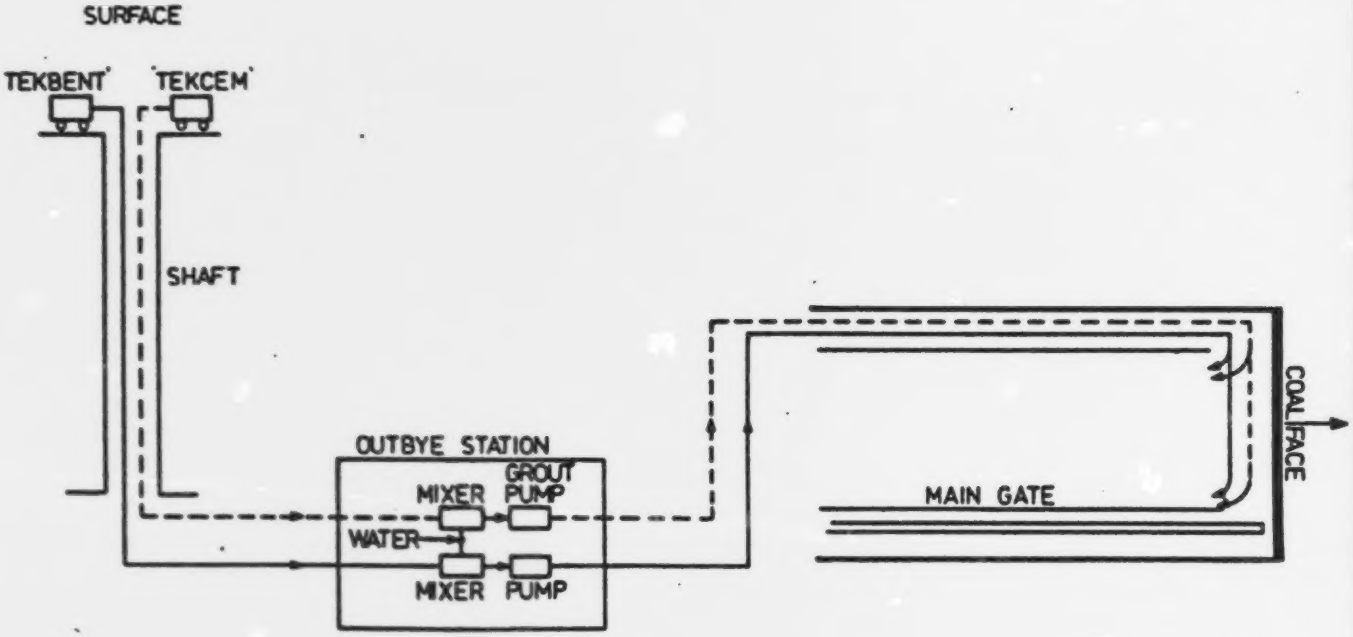

SURFACE
TEKBENT
TEKCEM
SHAFT
OUTBYE STATION
MIXER
GROUT PUMP
WATER
MIXER
PUMP
MAIN GATE
COAL FACE

FIGURE 6.17 Astrapak/Tekpak Pump Pack System
(Clark & Newson, 1985)

The gelled consistency of the Flashpack material permits the continuous spraying of the cement in layers to build the packwall without external containment The only packwall support provided is steel sheets suspended from the packhole supports to facilitate a smooth surface on the gateside of the packwall. The steel sheets are advanced with the packwall (Mills, 1984).

Most monolithic packing systems require rapid flushing of the pipe ranges following each packwall placement to prevent plugged pipes. The Flashpack system provides further advantages to other systems in that:

- the flyash, water, flocculant, bentonite slurry does not setup and will not require flushing of the line while in operation;
- retarding chemicals are used in the OPC to extend the setup time and therefore the pumping distance of the grout mixture. This extended set time accommodates flushing the grout line only once per day, not after every pour as with other systems.

A schematic diagram of the Flashpack system is given in Figure 6.18.

One recent (1984) modification to the Flashpak system is an experiment to mix the cement grout using the pozzalonic cement mixture of OPC and flyash rather than waiting to mix them at the packhole. The flocculant is piped to the packhole in a separate line where it is mixed with the cement grout in a special mixing gun (Mills, 1984). Trials of the system were conducted at Coventry Colliery in 1984/1985, however, no report of results is available.

Monolithic Pack - Summary

A consise summary of the available monolithic pump pack systems is presented in Table 6.5, outlining many of the important criteria of these systems. Several major differences can be summarized for these systems. The first of these is the requirement for an aggregate to form the pack material:

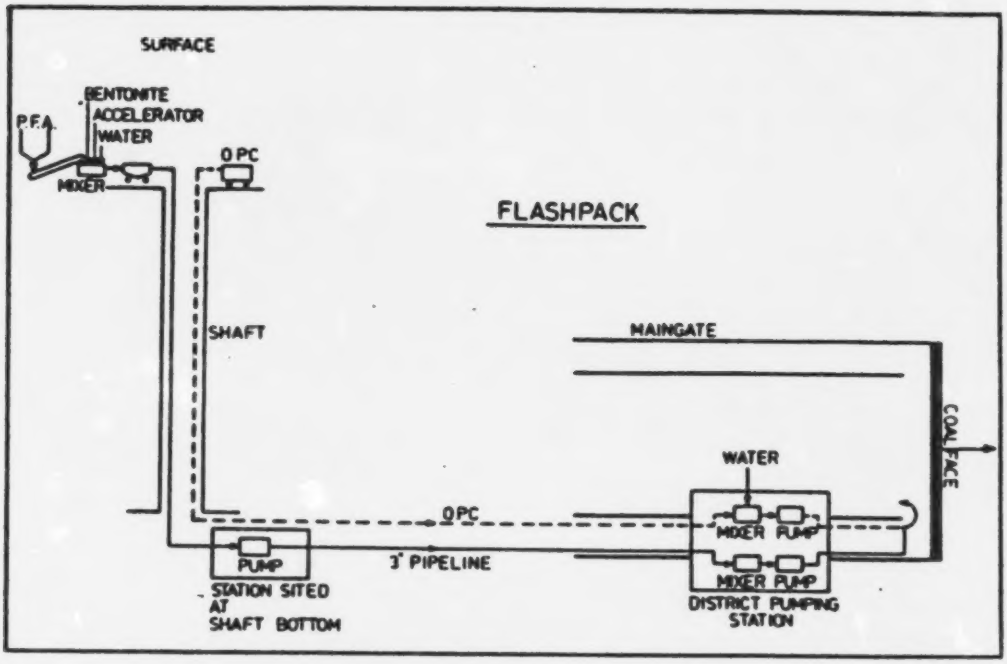

SURFACE
BENTONITE
ACCELERATOR
WATER
P.F.A.
MIXER
OPC
FLASHPACK
SHAFT
MAINGATE
COAL FACE
WATER
OPC
MIXER PUMP
MIXER PUMP
PUMP
3" PIPELINE
STATION SITED AT SHAFT BOTTOM
DISTRICT PUMPING STATION

FIGURE 6.18 Flashpack Pump Pack System
(Clark & Newson, 1985)

TABLE 6.5 Summary of Monolithic Pump Pak Systems

MAIN PRODUCTS / CHARACTERISTICS	PACK CONSOLIDATION[3] GP7	SYN. ANHYDRITE[1] ---	NATURAL ANHYDRITE[1] ---	THYSSEN[1] FLOWMAT	PACKBIND	AQUAPAK[1] AQUACEM	AQUABENT	TEKPAK[1] ASTRACEM	ASTRAPAK FLASHPACK[1] ASTRABENT	OPC	PFA
QUANTITY/m^3 OF PLACED PACK (kg)	1167	1700	2150	25 /	275	450 /	50	182 /	182	1150 (TOTAL)	
PIPELINE PUMPING LIFE (MINUTES)	N/A	N/A	N/A	IND /	30	45 /	IND	180 /	IND	120 /	IND
WATER CONTENT BY VOLUME (%)	40	27	10	45		85		92		50	
IMPORTED MATERIAL COSTS/m^3 OF PACK[4]	N/A	$230	$103	$110		$130		$115		$71	
AVERAGE SETTING TIME (MINUTES)	N/A	240	VERY QUICK	60		20		30		INSTANT GELATION	

COMP STRENGTH AT:	psi	Mpa	psi	MPa		psi	MPa	psi	MPa	psi	MPa	psi	MPA
2 HOURS	---	---	10	0.07	8 MPa	50	0.4	90	0.6	100	0.7	60	0.45
24 HOURS	44	0.3	870	6.0	5 HOURS	75	0.5	180	1.2	360	2.5	230	1.6
7 DAYS	246	1.7	1290	8.9		145	1.0	580	4.0	725	5.0	640	4.4

1 Clark and Newson (1985)
2 Nixon and Mills (1981)
3 Pozament Cement Ltd. (1985)
4 1982 Costs from (Clark & Newman) modified: (1983£ x $2.00/ £) x 1.33 (inflaction @ 10%/year) to give an estimate of current costs.
1980 Costs from (Nixon & Mills) modified: (1980 £ x $2.00/ £) x 1.61 (inflation @ 10%/year) to give an estimate of current costs.

Aggregate	No-Aggregate
Thyssen System	Astrapak (Tekpack)
Warbret System	Aquapak Flashpack

A second difference is the cost of the pack. As reported (Mills, 1984) the monolithic pump packs vary in cost.

Expensive	Inexpensive
Thysen	Flashpack
Warbret	
Astrapak (Tekpak)	
Aquapak	

7.0. CAVITY FILLING TECHNIQUES

The collapse of strata above mine openings (roadways and faces) creates cavities in the roof structure and causes major operational delays for remedial strata work. The deteriorated conditions of the strata prior to failure may result from natural means, e.g. faulting, or may result from failure of the rock material due to mining induced stresses. Techniques to deal with the problem of roof cavities can take two forms (Farmer, 1982; MRDE, 1981(a)):

- cavity filling (remedial);
- strata reinforcement (prevention).

Work has been done employing a combination of these techniques to fill the cavity and to reinforce the strata around the cavity simultaneously (Carr and Silvester, 1972).

7.1 Cavity Filling

The technology of cavity filling at the face and in roadways of coal mines has expanded beyond the traditional use of wooden chocks to include the following techniques:

- Strain Absorbent Modules (SAM's);
- Inflatables;
- Chemical Foams;
- Cementaceous Fill Material (Monolithic Fills).

Research work conducted by the Mining Research and Development Establishment (MRDE) of the British National Coal Board indicates that a support pressure of 7 kPa is adequate to stabilize most roof cavities (MRDE, 1981(a)) Similar documentation is provided by the Essen Research Centre for. Roof Support and Rock Mechanics in West Germany, which reports a pressure of 9.6 kPa is adequate to secure a cavity (Curth, 1974). This work is further confirmed in a report prepared for the U.S. Bureau of Mines which indicates pressures of 7 kPa to 14 kPa are sufficient for cavity filling (Hauser Laboratories).

From these works, it has been identified that the pressure required to support the cavity structure is quite limited and can be provided by simple structures which will provide only a fraction of the support provided by the traditional wood chocks, which are seemingly over-designed for the cavity filling application.

Strain-Absorbent Modules (SAM's)

Strain-absorbent modulues are wire basket structures constructed of wire mesh panels which are secured by steel helical binders. These baskets are constructed in various shapes and sizes to accommodate the efficient filling of cavities. The most common shapes are rectangular, cubic and pyrimidal (Figure 7.1). The bearing capacity of SAM's can be improved by increasing the stiffness of the basket through:

- the addition of internal wire mesh panels which are attached to the exterior panels of the SAM by steel helical binders (Figure 7.2);
- addition of mine waste material or a pumped foamed material inside the SAM.

SAM's have been adopted by the NCB for cavity filling; however, it still remains necessary for personnel to enter the unsecured cavity to install this support device. The major advantage the SAM's provide is to greatly reduce the time of installation relative to a wooden chock construction. Consequently, the exposure time in the cavity for installation of a SAM versus wooden chocks is reduced which consequently reduces the hazard to which the mine personnel are exposed.

The transportation of the SAM from the surface, where it is constructed, to the cavity location is facilitated by the collapsable construction of the basket provided by the steel helical binders. This construction also accommodates the easy placement of the basket in the cavity due to the reduced size of the collapsed unit. The lightweight version of the SAM, a 600 mm x 600 mm x 600 mm module constructed of 5 mm wire with a 50 mm x 50 mm mesh weighs only 14 kg (MRDE, 1981(b)), further accommodates ease of handling by the mine personnel.

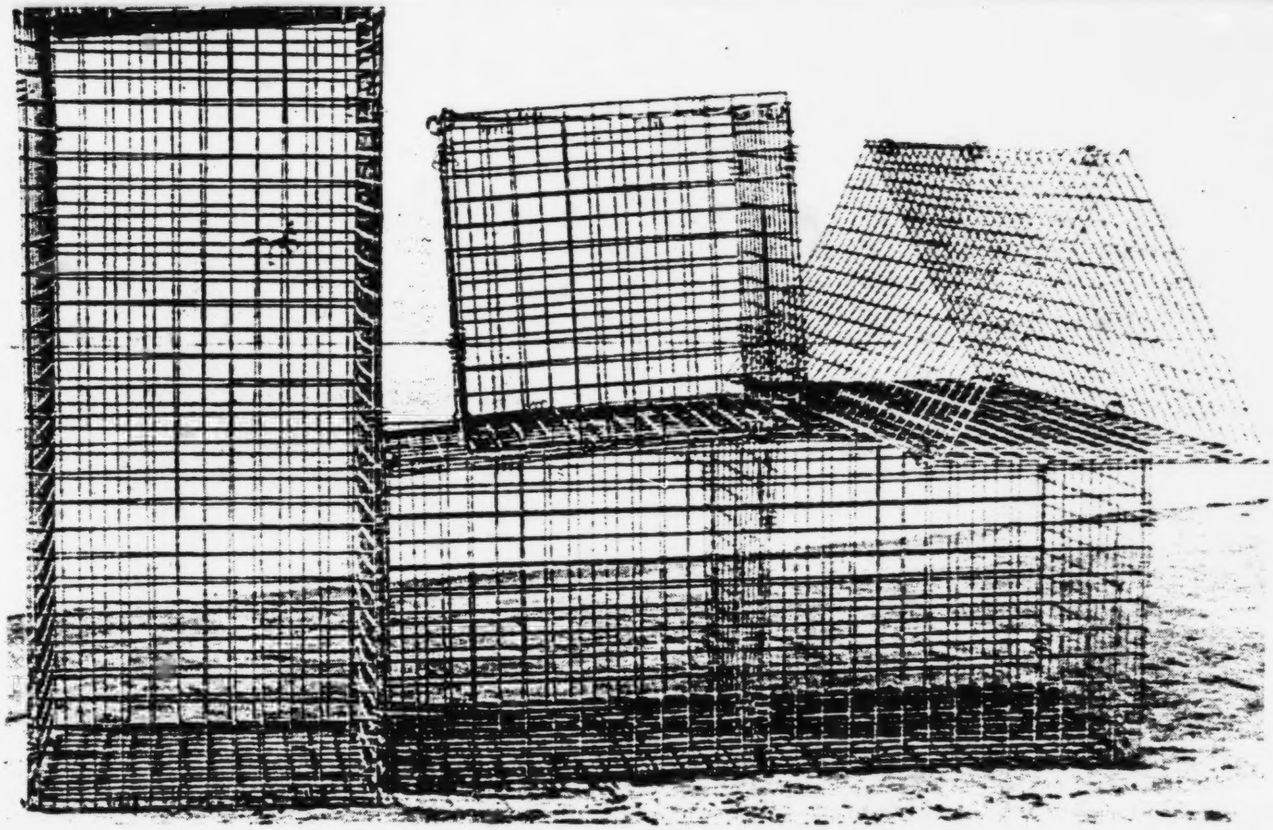
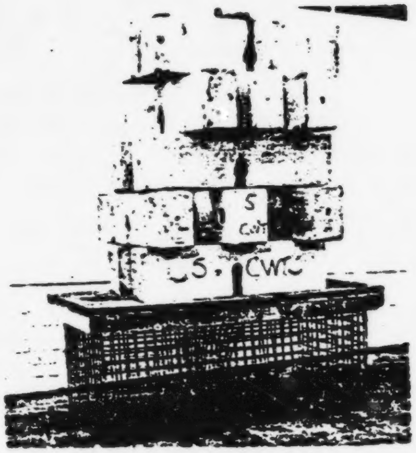
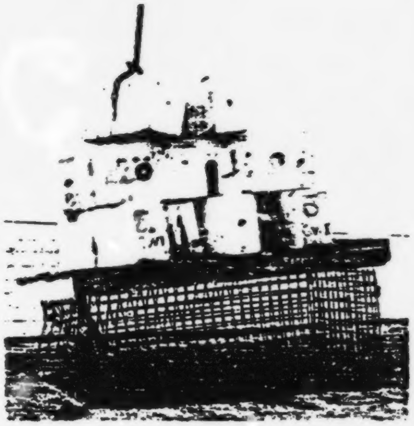


FIGURE 7.1 Strain Absorbent Modules
(Dalzell and Curth, 1985)



With Reinforcing
Panel (3 tonnes)



Without Reinforcing
Panel (1.5 tonnes)

FIGURE 7.2 Stain Absorbent Modules
(Reinforcement Panel Inside Module)

Inflatables

Air-filled inflatable structures are used extensively by the transportation industry to secure heavy loads while in transit. The mining industry has used this technology successfully in several situations:

- cavity-filling in coal mines (MRDE, 1981(a); Farmer, 1982);
- temporary stoppings for isolation and rescue activities when fighting fires in metal mines (Thimons and Kissel, 1976);
- temporary support structures for coal mine roof in room and pillar mines (Curth, 1974).

Investigations of inflatables for cavity-filling work has been conducted by the USBM (Dalzell and Curth, 1985) and the MRDE (MRDE, 1981(a)). The types of inflatables which have been tested are outlined in Table 7.1, and illustrated in Figure 7.3.

The inflatables (not including dunnage bags) are reported by the investigating agencies to provide a system of cavity-filling which:

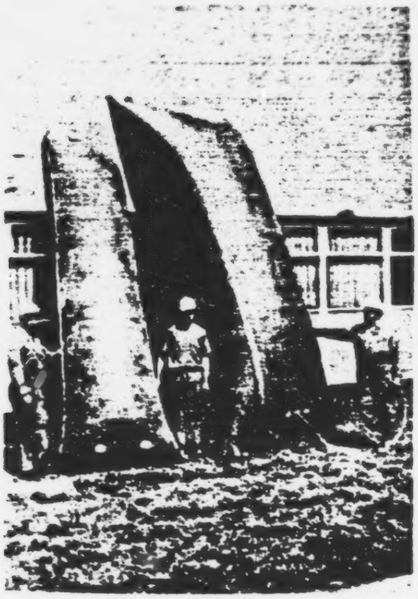
- is lightweight and compact for handling;
- is easy to install (hand/foot pump or compressed air);
- provides excellent contact with the cavity walls and roof (a large cavity may be filled by using several inflatables or by combining an inflatable with a pumpable cementaceous material);
- can be recovered when equipped with the necessary valving (difficult and dangerous on faces equipped with shield supports).

It has been proposed by the MRDE (Farmer, 1982) to resolve the problem of punctured inflatables by filling the inflatable with a low density, quick setting cementaceous material. Current work by the MRDE in search of an elastic, low density cementaceous material is concentrating on two methods:

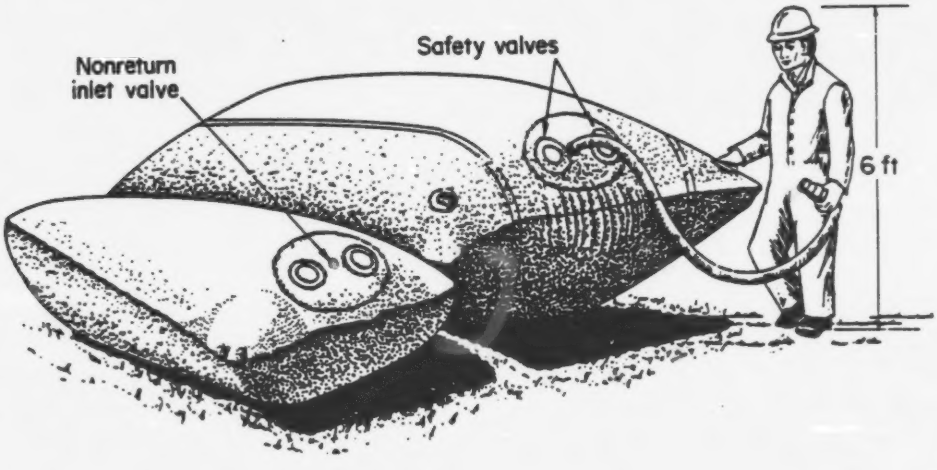
TABLE 7.1 Air-Filled Inflatable Structures for Cavity Filling In Coal Mines

Investigating Agency	Construction	Inflated Pressures	Comments
NCB & USBM	Neoprene-coated nylon bladder	6.9 kPa	-expensive $1,500 - $3,000
NCB & USBM	Polyvinyl-coated nylon bladder	6.9 kPa	-can be torn
NCB & USBM	Mylar-coated nylon bladder	6.9 kPa	-valve arrangement to permit recovery when possible.
USBM	Dunnage bags (kraft paper coated polyethylene bladder)	56 kPa (normal pressure)	-very rigid, inelastic to tears, not suitable for cavity filling
	Dunnage bags (kraft paper coated polyethylene bladder)	12 kPa (low pressure)	-much more suitable for cavity-filling but tears easily ($20 - $50).

1 (MRDE, 1981(a))
2 (Hauser Laboratories)
3 (Thimons and Kissel, 1976)
4 (Dalzell and Curth, 1985)



(a) Inflatables on Surface Trial
(MRDE, 1981(a))


Safety valves
Nonreturn inlet valve
6 ft

(b) Schematic of Inflatables for Cavity Filling
(Dalzell and Curth, 1985

FIGURE 7.3 Inflatables Suitable for Mining Industry

- mixing foam in liquid cement;
- high aeration ratio of standard cementaceous products used in the mine (Aerostem).

Chemical Foams

Preliminary cavity filling work with chemical foams in West Germany employed two foamed materials; polyurethane and phenolic resins. Neither system provided the support characteristics desired nor conformed with health and safety regulations and were eliminated in favour of ureaformaldehyde foam.

Urea-Formaldehyde

Coal mine cavity filling in West Germany and France, is currently and has for 25 years been accomplished using a ureaformaldehyde foam known by the commercial names "Isoschaum" (Germany) or "Igloneige" (France). This product has been used by the NCB for cavity filling; however, the Hazard Assessment Committee of the NCB, in 1982, restricted its use to only face line cavity- filling under strict supervision (Silvester, 1982). Urea-formaldehyde foam has been used at CBDC coal mines as a packwall sealant. Current work to eliminate ventilation air leakages through the packs by the introduction of monolithic pack systems may eliminate the requirement for this foam in CBDC coal mines.

The major concern in the U.K., U.S. and Canada over the use of urea-formaldehyde in mines is the risk of exposure to formaldehyde gases which are liberated by the product. Tests conducted by the NCB while advancing a face under a urea-formaldehyde foam filled cavity indicated a concentration of 1 to 2 parts per million (ppm) of formaldehyde gas (Dalzell and Curth, 1985). The Threshold Limit Valve for formaldehyde gas is 2 ppm (Silvester, 1982; Dalzall and Curth, 1985). Also, the U.S. National Institute of Occupational Safety and Health (NIOSH) classifies formaldehyde as a potential occupational carcinogen (Dalzell and Curth, 1985).

Despite the excellent physical properties of urea-formaldehyde foam as a cavity-filling material:

- 25:1 expansion ratio of its liquidous state by volume;
- compressive strength - 5 tonnes/m^3 in 48 hours;
- early strength - hardens in 1 hour;
- water resistant;
- applied remotely by pumping through a gun - no personnel in the cavity (safety);
- highly elastic;
- forms to the shape of the cavity;
- no adhesive bond to the strata.

It is not permitted to be used in the underground mines of U.K., U.S. and Canada. Consequently, further details of this system will not be discussed in this report.

Sodium Silicate

The MRDE conducted an investigation (1980 - 1984) into the replacement of urea-formaldehyde with sodium silicate as a chemical foam for cavity filling (MRDE, 1981(c); MRDE, 1982). The system comprises a two liquid mixture of sodium silicate and a solution of magnesium and zinc salts as the hardener. The foaming action is created by the addition of a small quantity of an organic surfactant and and the injection of compressed air into a special gun with the two solutions. Sodium silicate foam has an expansion ratio of 8:1 (25:1 for urea formaldehyde). It therefore requires approximately three times the volume of sodium silicate to fill a cavity than with urea-formaldehyde. Consequently, sodium silicate represents a more expensive cavity filling process.

Also during trials of a urea-formaldehyde/sodium silicate foam generator, developed by the MRDE, the production rate of sodium silicate (16 m^3/hr) was approximately one-half the rate of urea formaldehyde (30 m^3/hr) (MRDE, 1982). During trials at three U.K. colleries (Daw Mills, Kiverton Park and Ollerton) a problem with stablizing the sodium silicate hardner was experienced. No solution to the problem was determined and the project to use sodium silicate as a chemical foam for cavity filling was delayed (MRDE, 1982).

Natural Anhydrite

It is reported (Dalzell and Curth, 1984) that strata replacement work at the face has been accomplished in West Germany using a pneumatically stowed natural anhydrite material. This work was completed, using a strandard pneumatic stowing system for gateside strip pack work, and a rudimentary cavity floor constructed over the face supports to contain the anhydrite while it set.

Cementitious Products

Research by the MRDE on the development of a cement based cavity filling material has generated a selection of alternative materials, Table 7.2. These materials provide many of the following features as established by the MRDE:

- high expansion ratio (support volume:volume of liquid constituents);
- noncombustible material;
- inexpensive;
- placed with simple equipment;
- cementing agent - ordinary Portland Cement;
- materials possess a high yielding property without cracking.

Despite the low compressive strength of these cementaceous materials, they do provide adequate restraint to stabilize a cavity.

Foamed Cement

Efforts to provide this cementitious product for cavity filling are based upon the technology of aerated (foamed) cement generated by the addition of a foam stabilizing agent added to OPC and injecting air into the cement.

The aerated cement retains its liquid properties and therefore requires a watertight bag or substantial shuttering installed in the cavity to retain this fill material. The cement is pumped into the cavity by an approved concrete pump.

TABLE 7.2 Cementitious Material for Cavity Filling

Material Character	Components	Company	Expansion Ratio	Gel Time	Set Time	Compressive Strength	Pumping Characteristics	Comments
Foamed Cement	air entrained OPC	Fasroc CBP Ltd. (re-searched)	5:1	2 hr	7 days	mix dependent	liquid	requires heavy foam work
Aerostem	Hardstem + sodium bicarbonate + water	British Gypsum Ltd.	1.6:1	2 hr	7 days	N/A	liquid	cavity floor
Cavity-fill 5	HESOPC + aluminum sulphate + flyash + water	Pozament Ltd.	N/A	15min.	1 1/4 hr	.6 MPa/24 hr.	thixotropic	requires rudimentary shuttering
Aqualight	Aquacent soda ashe + foaming agent + water	Pozament Ltd.	15:1	2min.	24 hrs.	.07 MPa/24 hr.	thixotropic	requires rudimentary shuttering
Flashpack	HESOPC + flyash + aluminum sulphate + water (ratios vary)	Mixed on site	1:1	instantaneous		.54 MPa/2 hr. .95 MPa/4 hr.	2 liquids sets instantly	requires rudimentary shuttering

Aerostem

Aerostem is a proprietary cement mix marketed by British Gypsum Limited. It is composed of sodium bicarbonate and Hardstem (gypsum plaster from British Gypsum Ltd.). The mixture forms large concentrations of carbon dioxide gas when mixed with water which are entrained within the cement to form an aerated cement mixture with a strength capable of supporting a cavity. Cavity fillng work conducted with Aerostem has employed a Monopump to place the material in the cavity through a flexible hose.

Cavityfill 5

This product is a thixotropic grout material researched and marketed by Pozament Cement Ltd. in co-operation with the MRDE. The thixotropic property is achieved by the addition of aluminum sulphate and flyash to OPC grout. This property allows the modified grout material to be pumped as a liquid under pressure, but when released into the cavity it gels and reaches its initial set quickly. This quick gel property eliminates the requirements for a bag in the cavity to retain the cementitious material. Cavityfill 5 is able to span a gap of 5 cm in the artificial floor used to support the cavity filling material (Mills, 1984).

The product is not aerated and in an effort to reduce the cost, flyash is used as a pozzolanic substitute for a large quantity of the OPC. Recommendations for pumping Cavityfill 5 include restricting the pumping distance to 360 m in a 5 cm diameter hose using a properly sized placing machine. No time delay between mixing and pumping can be tolerated due to the short setup time.

Aqualight

A recent development by the MRDE is the foamed cement product Aqualight designed specifically for cavity filling and roadway backfilling. The product is currently approved by the NCB as a cavity filling material and a 1984 (October) estimate of 2000 m^3 usage of Aqualight for cavity filling indicates its general acceptance (Mills, 1984(a)).

Aqualight is a powder mixture of Aquacem (Pozament Cement Ltd.), soda ash and a protein based foam stabilizing agent. During the pumping action water and air are introduced into the powder mixture to impregnate air bubbles in the cement mixture and create an aerated cement grout material. In operation, Aqualight powder is fed into a hopper below which an Archimedean screw feeds the required quantity of powder into a mixing trough where a metered volume of water is mixed. A Monopump is then used to draw the grout mixture and a large volume of air to be delivered to the cavity. During the pumping action, air is dispersed as small bubbles in the grout mixture. Work conducted by the MRDE was done using a two speed Langley placer machine which is capable of pumping 8.8 or 13 m^3/hr of Aqualight to the cavity (Mills, 1984(a)).

Flashpack

The Flashpack cementitious material (described in Section 6.7, Monolithic Packs) has been considered for cavity-filling work. This intended usage for Flyash Cement is evidenced in the British patent application (GB2128179A)

It is reported (Mills, 1984 (b)) to be suitable for filling a cavity by building up successive layers of the flyash cements through spraying techniques.

7.2 Strata Reinforcement Techniques

Strata reinforcement techniques will not be discussed in detail as they do not directly replace wood for cavity filling application. The techniques represent a preventive method to stabilize the strata prior to the cavity formation therehereby eliminates the need to fill the cavity. A listing of these strata reinforcement techniques follows:

- strata bolting;
- strata dowelling;
- injection dowelling;
- strata injection;
- strata infusion;
- truss bolting.

A condensed report on these techniques can be found in Sylvester (1982).

8.0 NEW FACE DEVELOPMENT/STRIPPING COMPLETED FACE

Temporary ground support is required on the face line during the setting and removal of the longwall face equipment. This support can be provided by several techniques which eliminates the requirement for wood:

1. strata reinforcement

2. steel prop and bar with wire mesh and steel cables.

Strata Reinforcement

The new face line constitutes a single opening which has been stabilized in coal mines in the U.S. and France by strata reinforcement techniques using fully bonded steel dowels in the roof and fully bonded wooden or fiberglass dowels within the cutting horizon set during the face line development (Murphy, 1981). The length of the wooden/fiberglass dowels vary between 2.4 m and 4.0 m depending on the strata conditions. When properly implemented, the strata reinforcement technique simplifies the installation of the longwall equipment as there are no props, posts, etc., to obstruct the face equipment installation.

Strata reinforcement can also be used at the completion of the face to secure the work area for the removal of equipment from the face line. This practice requires the forward reinforcement of the roof strata by fully-bonded dowels set during the last two or three cuts of the face.

Steel Prop and Bar with Wire Mesh and Steel Cable

A technique for face line development used in West Germany involves the application of a temporary support system which includes steel props and bars in conjunction with welded wire mesh, as shown in Figure 8.1.

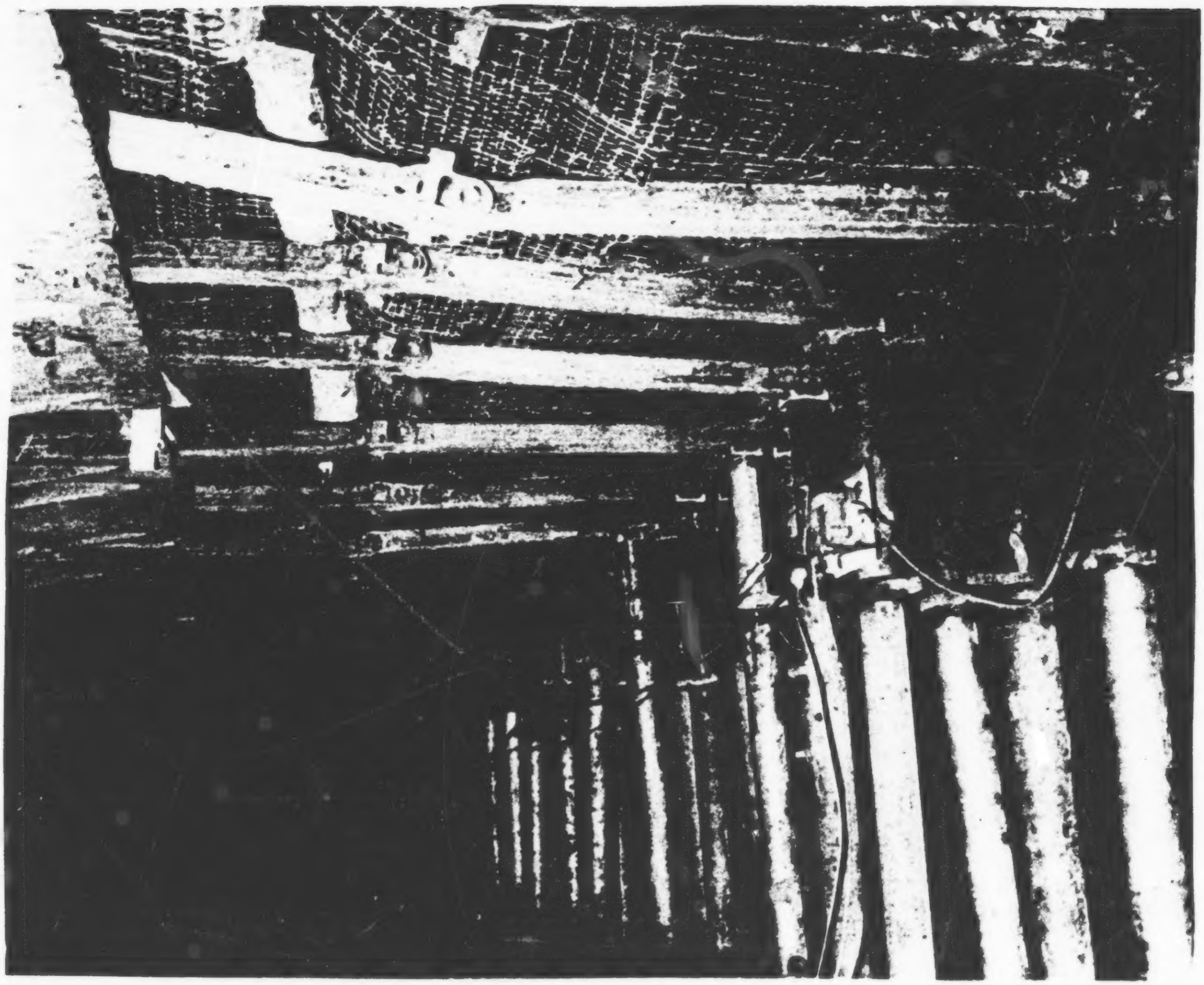


FIGURE 8.1 Steel Prop and Bar with Wire Mesh
Used To Develop a New Face
(Drahtwerke Rosler Soest GmbH)

The face supports are set against the steel bars which permit the recovery of the props. The bars are also recoverable as the wire mesh isolates the bars from the gob area.

A similar system is employed at the completion of the longwall panel. Wire mesh is secured as a roof cover during the last 10 to 12 cuts by running welded wire mesh over the face supports, Figure 7.2. This mesh is strengthened with steel cables runing the length of the face, between the wire mesh and the face supports, and placed during the last 2 cuts of the face, Figure 7.3. As the powered face supports are removed, the steel cable and wire mesh cover provide a stable work area, Figure 7.4. Temporary props, (of steel or wood) may be used in the immediate work area for additional support.

This discussion has concentrated on powered face support longwall systems. Similar techniques using welded wire mesh exist for single prop longwall systems.

FIGURE 8.2 Placing Wire Mesh Over Shield Supports During The Last 10 to 20 Cuts (Drahtwerke Rosler Soest GmbH).

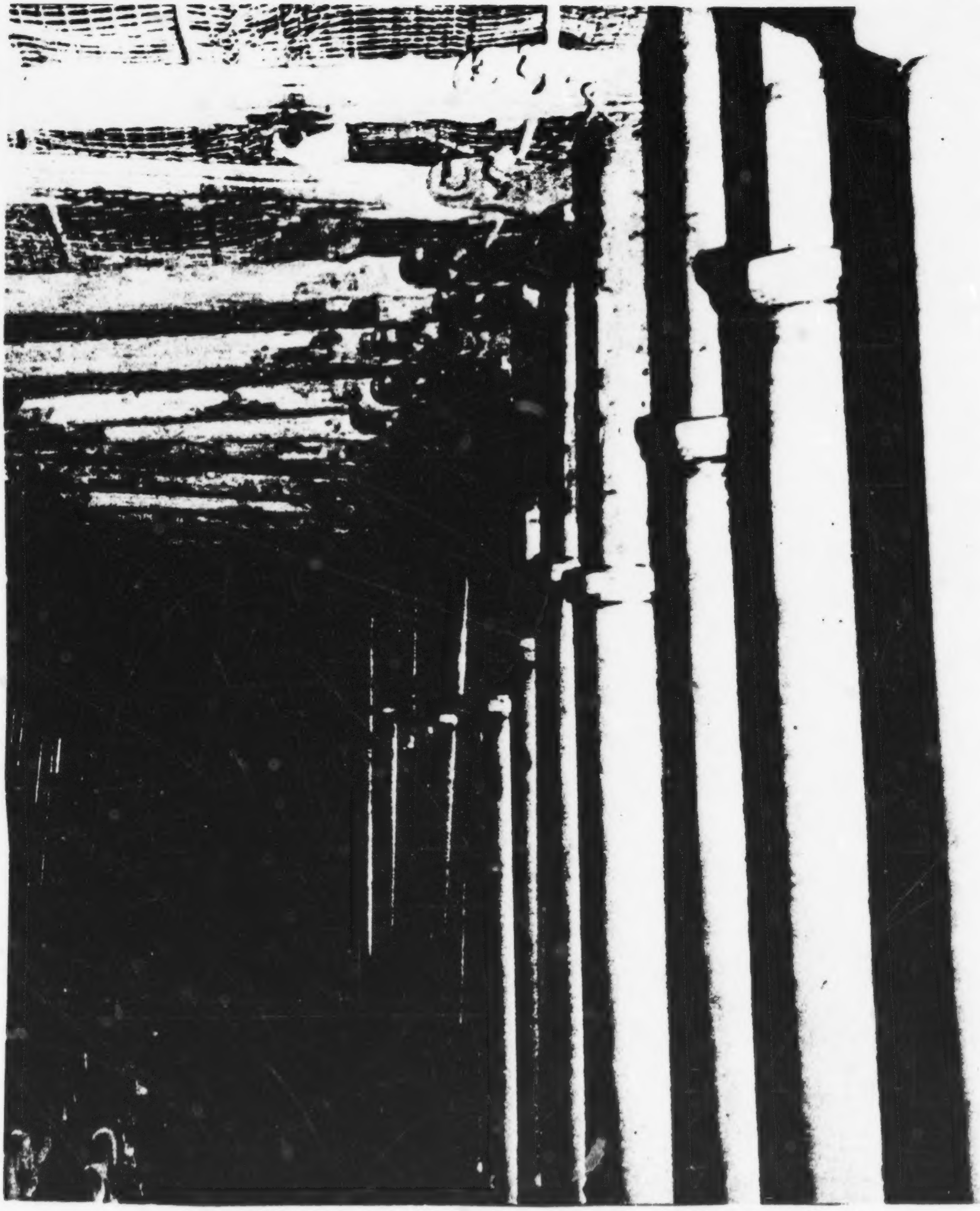


FIGURE 8.3 Steel Prop and Bar With Wire Mesh and Steel Cable Used at the Completion of the Face to Accommodate Equipment Removal (Drahtwerke Rosler Soest GmbH).

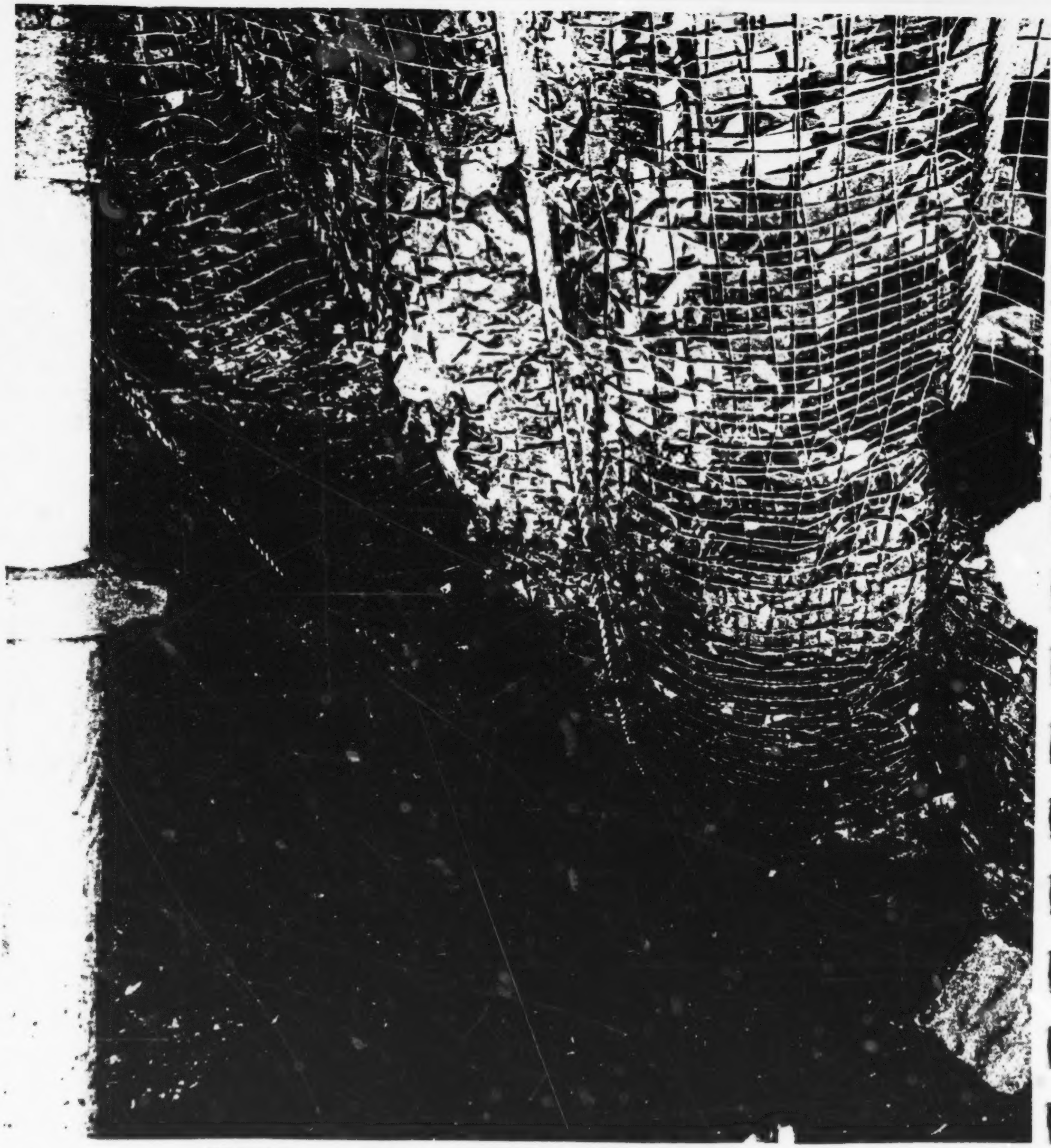


FIGURE 8.4 Stable Work Area for Stripping Longwall Face Equipment (Drahtwerke Roseler Soest GmbH).

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NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES

PHASE II - PART II

REVIEW OF INDIGENOUS MATERIALS

By

JACQUES, WHITFORD AND ASSOCIATES LIMITED

With

P. LANE AND ASSOCIATES LIMITED

DSS FILE NUMBER: 07SQ.23440-5-9009
DSS CONTRACT SERIAL NUMBER: 0SQ85-00032
SCIENTIFIC AUTHORITY: MR. G.A. HASLETT, P.ENG.

Halifax, Nova Scotia

March, 1986

SUMMARY

A review of technologies for wood replacement in underground coal mines has highlighted numerous alternatives that could be pursued by CBDC. To maximize the benefits to the regional area of Cape Breton Island, Nova Scotia, consideration was given to the use of indigenous materials of Cape Breton Island, Nova Scotia, and the Maritime Provinces. Based on these criteria, a set of wood replacement recommendations is made employing a predictive, functional "FIRE RISK INDEX" model developed for this study. This model is founded on a descriptive fault tree risk analysis model developed for the CBDC coal mines within the scope of this report (Phase I).

A prioritization has been proposed for wood replacement at CBDC. This ranking, in descending order of importance, is as follows:

- lagging;
- wooden packs;
- cavity filling material;
- construction material;
- rail ties;
- remedial support member.

Two alternative systems have been identified for use in gateside packs, cavity filling, and construction materials; one based on fly ash cements and the other based on anhydrite. The anhydrite and fly ash are readily available from Cape Breton Island and the OPC is manufactured in mainland Nova Scotia. Both systems (fly ash cement and anhydrite) can be used to replace the majority of wood usage in gateside packs, cavity filling and construction materials using technologies which have been identified.

The materials costs for each of these above techniques have been provided.

The Health and Safety issues for each of these systems are identified.

Though it is beyond the scope of this wood replacement analysis, recommendations are made to surface coat "standing" timber in permanent airways with appropriate "mine sealant" materials to reduce fire hazards in the mine.

It is recommended to replace wood lagging with welding wire mesh panels. Effective blocking and backfilling of wire mesh lagged arch supports can be best accomplished using grout-filled envelopes or complete backfilling technologies. Sprayed concrete lining (shotcrete or gunite) could also be used as a roadway lining with arch supports and weld mesh lagging; however, this technique can only be used in roadways which experience limited deformation to minimize repair costs.

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1.0 INTRODUCTION

Wood has historically been used in underground mines in numerous support capacities and as a construction material. Its traditional advantages of:

- high strength/weight ratio;
- ease of shaping and assembly in the underground with limited tools;
- low cost;

must be considered in contrast to the increased risk of fire created by wood in an underground environment. The low ignition temperature of wood and the rapid rate of flame spread on the surface of untreated wood make this material particularly hazardous in areas of the mine where ignitions are possible. These problems are exacerbated by the manner in which the wood is used; such as:

- concentrated usage of wood in specific areas of the mine which represent a large fuel load in the event of an ignition;
- continuous application of timber through extensive areas of the mine which represent a continuous flame path to rapidly spread a fire through the mine.

Extensive work has been conducted internationally to minimize the potential fire hazard created by wood in the underground mine environment. This work has developed a variety of techniques within each of the following methods:

- to treat mine timbers by chemical impregnation processes or surface treatment processes to render the wood resistant to fire;
- to replace wood with suitable, non-combustible materials;
- to employ alternative mining technologies to eliminate the requirement for wood.

In West Germany and the United Kingdom the shortage in domestic supply of mine timber has accelerated the search for alternative materials and technologies for economic reasons as well as for mine safety reasons. Consequently, a great deal of the work was conducted in those countries. A review of the alternative materials and technologies developed to reduce the fire hazard created by wood in underground coal mines is presented in Phase II - Part I of this report. A brief summary of the above review is included in this report (Phase II - Part II) to facilitate an evaluation of indigenous materials suitable as a replacement for wood in Cape Breton Development Corporation (CBDC) coal mines.

An evaluation of the potential risk associated with the current uses of wood at CBDC is presented. The evaluation was facilitated by work conducted on a descriptive fault tree risk analysis model completed in Phase I of this report. A priority listing for wood replacement in the CBDC coal mines is proposed.

1.1 Purpose of Study

The purpose of this study is to investigate the potential use of local resources, indigenous to Cape Breton Island, Nova Scotia, and the Maritime Provinces, in the development of non-combustible alternatives and substitutes to the use of wood in CBDC coal mines.

A preliminary materials cost analysis is conducted on the options that are deemed appropriate for CBDC. Also a review of health and safety issues associated with these alternatives techniques and substitute materials is presented.

1.2 Scope of Study

The investigation of local materials is concentrated within Cape Breton Island; however, consideration is given to materials available throughout Nova Scotia and the Maritime Provinces. A brief description is provided of the industrial processes required to utilize locally available materials to replace wood in CBDC mines. Several of these processes do not currently exist in the region and therefore, if implemented, would represent an expansion to the industrial base of the province. No attempt will be made to evaluate the market potential or economic viability of such an industrial plant.

2.0 IDENTIFICATION OF LOCAL MATERIALS

In Phase II - Part I of this report, a review was conducted of non-combustible replacement materials, methods and techniques to reduce the usage of wood in underground coal mines. This work identified numerous replacement systems for traditional wood uses, such as:

- construction materials;
- lagging boards;
- gateside packwall construction;
- cavity stabilization; and
- new face development.

A majority of the materials and technologies identified are available as proprietary products in Europe, the United Kingdom or the United States and would necessarily be imported for use in CBDC mines.

The lack of domestic supply for most of these replacement systems creates a potential for the development of new industry in Nova Scotia to produce non-combustible materials and/or products, based on a known technology, for use in CBDC coal mines. The supply of raw materials to this industry represents additional economic benefit to the mine area if it is sourced from local supplies. In an effort to evaluate the potential market for indigenous materials, under this scenario, a materials requirement analysis for each of the alternative replacement systems was conducted. Based on these materials requirements, an extensive investigation of local materials indigenous to Cape Breton Island, Nova Scotia, and the Maritime Provinces was conducted. This review indicated the following resources are compatible:

- CBDC Coal Mine Product and By-products:
  - Coal
  - Mine Waste
  - Wash Plant Refuse

- Indigenous Mineral Resources - Mine Production and By-products:
  - Anhydrite
  - Gypsum
  - Limestone
  - Clay
  - Shale
  - Aggregate
  - Mine Waste
  - Mill Tailings

- Industrial Process By-products:
  - Fly Ash
  - Metallurgical Slags

- Manufactured Products:
  - Ordinary Portland Cement
  - Sodium Silicate
  - Miscellaneous Chemicals
  - Steel

Table 2.1 presents a cross reference between the local materials indigenous to the region and the associated non-combustible alternatives identified in Phase II - Part I. Each of these categories of local materials will be discussed at a preliminary stage in the following manner:

- applications for the material;
- requirements of the material; and
- discussion.

This information is designed to preview the potential to use the subject materials as a non-combustible replacement for wood in CBDC coal mines. Following this preliminary information on each category of material, a detailed analysis will be conducted on the more viable alternatives.

It is noted that the local materials which are unsuitable for obvious reasons are eliminated from further consideration at the preliminary discussion stage. These materials have been included for completeness of this report.

TABLE 2.1: Wood Replacement Technologies and Indigenous Material Usage

INDIGENOUS MATERIAL USAGE		CEDC Coal Mine Product & Byproduct				Indigenous Mineral Resources Mine Production & Byproducts				
PHASE I REFER-ENCE NO.	WOOD REPLACEMENT TECHNOLOGY	R.O.M. Coal	Mine Waste	Wash Plant Refuse	Anhydrite (Natural & Synthetic)	Gypsum	Limestone	Clay	Shale	Aggregate
3.0	FIRE RETARDANT TREATMENTS									
3.1	Chemical Impregnation									
3.1	Precharring									
3.2	Chemical Coating						X			
3.2	Mine Sealant Coatings					X	X			
3.2	Polymer Based Coatings									
3.2	Intumescent Paint Coatings									
4.0	CONSTRUCTION MATERIALS									
	Normal Weight Concrete Block									X
	Autoclave Aerated Concrete Block						X			
	Fibre-reinforced Shotcrete Panels									X
	Anhydrite Stoppings				X					
	Steel panels & Framing									
5.0	LAGGING MATERIALS									
5.1	Corrugated Steel Sheets									
5.1	Steel Liner Plates									
5.1	Wire Mesh Lagging									
5.1	Strutlag									
5.1	Rockbolts & Wire Mesh									
5.2	Complete Roadway Backfilling				X					X
5.2	Partial Roadway Backfilling									
5.2	Sprayed Concrete									X
5.2	Precast Lagging Boards									
6.0	GATESIDE PACKWALL CONSTRUCTION									
6.4	Precast Concrete Block									
	Autoclave Aerated Concrete Block						X			
	Steel-fibre Reinforced Concrete Block									X
	Reinforced Light-Weight Aggregate Concrete Block							X	X	
6.5	Pneumatically Placed Packs									
	Complete Face Backfilling		X	X	X					
	Strip Packwall Construction				X		X			
6.6	Mechanically Placed Packs									
	Slusher, Blade & Ram		X							
6.7	Hydromechanically Placed Packs									
	Synthetic Anydrite Packs				X					
	Pack Consolidation	X	X							
	Thyssen System	X	X				X			
	Warbret System	X	X							
	Aquapak System									
	Astrapak (Tekpak) System									
	Flashpack System									
7.0	CAVITY STABILIZATION TECHNIQUES									
7.1	Anhydrite									
	Strain Absorbent Modules									
	Inflatables									
	Chemical Foams									
	Cementaceous Products									
	Foamed Cement								X	
	Aqualight					X				
	Cavityfill B									
	Flyash Cement									
7.2	Strata Reinforcement									
	Grout Injection									
	Strata Dowelling									
8.0	NEW FACE DEVELOPMENT/ STRIPPING COMPLETED FACE									
	Strata Reinforcement									
	Wire Mesh & Steel Cable									

al Usage

ous Mineral Resources Production & Byproducts					Industrial Process Byproducts		Manufactured Materials				Comments
Clay	Shale	Aggregate	Mine Waste	Mine Tailings	Flyash	Metallurgical Slags	OPC - Grouts - Cement	Sodium Silicate	Misc. Chemicals	Steel	
									X		
									X		
								X	X		
							X		X		
									X		
									X		
		X					X				
					X	X	X		X		
		X					X			X	- Wire mesh panel structure steel or fibreglass fibres
										X	- Wire mesh panel structure
										X	
										X	
										X	
										X	
										X	
										X	
		X			X		X		X	X	- Wire mesh lagging material used - High early strength
					X		X		X		- Textile grout envelopes required
		X					X		X	X	- Steel firbre reinforced
							X		X		
					X	X	X		X		
		X					X		X		
X	X					X					- Sintered clay/shale aggregate - Foamed slag aggregate
			X	X	X				X		- Flotation slurrys also used to increase compaction
					X				X		
									X		- Synthetic Anhydrite; Water proof pack bag required
							X		X		- highly permeable grout
					X		X		X		- Pack bag & wire mesh forms
							X				
							X		X		
							X		X		
					X		X		X		
										X	- Can be filled with a foamed cement
											- Air tight textile bag; Can be filled with foamed cement
								X	X		- UFFI predominant
	X										
					X		X		X		
					X		X		X		
							X		X		
							X			X	- Steel dowels; Fibreglass dowels; Wooden dowels
							X		X		
										X	

3.0 CBDC COAL MINE PRODUCTION AND BY-PRODUCTS

Three of the products generated by CBDC coal mine operations can potentially be used to develop a material/technique to replace wood in coal mines. These products are:

- run-of-mine (ROM) coal;
- coal mine waste; and
- wash plant tailings.

The category for CBDC products was separated from other similar materials for several reasons that make them unique:

- No cost of materials would be associated with this option as these are produced by CBDC (unless upgrading was required).
- The close proximity of this product to its point of use and the limited transportation which can be conducted using existing CBDC equipment.

3.1 CBDC Run-of-Mine (ROM) Coal

Discussion

The only identified use of ROM Coal as a replacement for wood is as an aggregate material (screened to -25 mm) for monolithic packwall construction by the Thyssen, Warbret, or Pack Consolidation techniques. This use of ROM coal represents a loss of coal production and in European mines its application has been curtailed in favour of improved methods of packwall construction. In view of the fact that the European mining community has found improved monolithic pack systems that do not require ROM coal (or any aggregate), it is concluded that it would be more advantageous to CBDC to consider these new technologies than to pursue either the Thyssen or Warbret or Pack Consolidation systems employing ROM coal.

Consequently, further discussion on the use of ROM coal in monolithic pack systems is not conducted.

3.2 CBDC Coal Mine Waste

Discussion

The coal mine waste created at CBDC is not conveyed to the surface as a separate waste product. Gateside ripping debris is either disposed in the packhole where it serves to assist the support resistance of the packwall; or, it is conveyed with the coal to the coal preparation plant where it is cleaned and discarded as an ash material.

As a result of this operating policy, very little direct coal mine waste is available for either of the identified applications of coal mine wastes, which include:

- manufacture of reinforced lightweight aggregate concrete block;
- complete face backfilling;
- mechanically placed packs;
- monolithic pack systems (Pack Consolidation, Thyssen or Warbret System).

3.3 Wash-Plant Tailings

Applications

Coal wash-plant tailings (refuse) is used in two applications related to longwall coal mining:

- complete backfilling of the face by pneumatic stowing; and
- manufacture of lightweight aggregate for production of lightweight aggregate concrete block.

One additional use for refuse material, not identified in the literature, is as an aggregate in shotcrete.

The development of a cemented coal refuse backfill material for U.S. room and pillar mines is not suitable for longwall techniques and will not be discussed in this report.

The complete backfilling of a longwall face is used in European coal mines to minimize subsidence related damage over longwall panels. This practice requires large volume of material to be transported underground and is justified only when objects overlying the mining area are sensitive to subsidence (eg. rivers, acquifers, highways, large buildings, etc.). Complete backfilling is also used to minimize damage to underground workings by reducing mining induced stresses throughout the mine structure. Improved ventilation through the elimination of gob leakage is also accomplished by a dense solid stowing.

The development of a lightweight aggregate concrete block for packwall construction met with limited success during trials in the UK due to a catastrophic failure mechanism after yield load. Applications for this product could be made in a mortared block construction for isolation rooms, sheds, stoppings, etc. This limited use would not justify the cost of necessary plant and equipment for this manufacturing process.

Requirements

Use of Refuse for Complete Backfilling

It is reported (Rauer, 1983) that the sizing of stowing material is of importance to obtain a densely stowed pack of excellent load resistance. The size consist recommended comprises particles up to 80 mm; however, with recent work on a 225 mm diameter stowing pipe, over-size particles up to 120 mm can be used. The ideal particle sizing would be one which matches a good characteristic curve for concrete aggregate (Fuller-curve) Figure 3.1.

A proposed system for pneumatically placed backfill for longwall coal mines in the US (Bucek, 1980) used a blend of 60 percent coarse refuse (-76.2 mm + 6.4 mm) and 40 percent dewatered fine refuse (-6.4 mm with less than 25 percent of the fine refuse -28 mesh). This design of backfill was based on work done in South Wales (Lansdown, 1949).

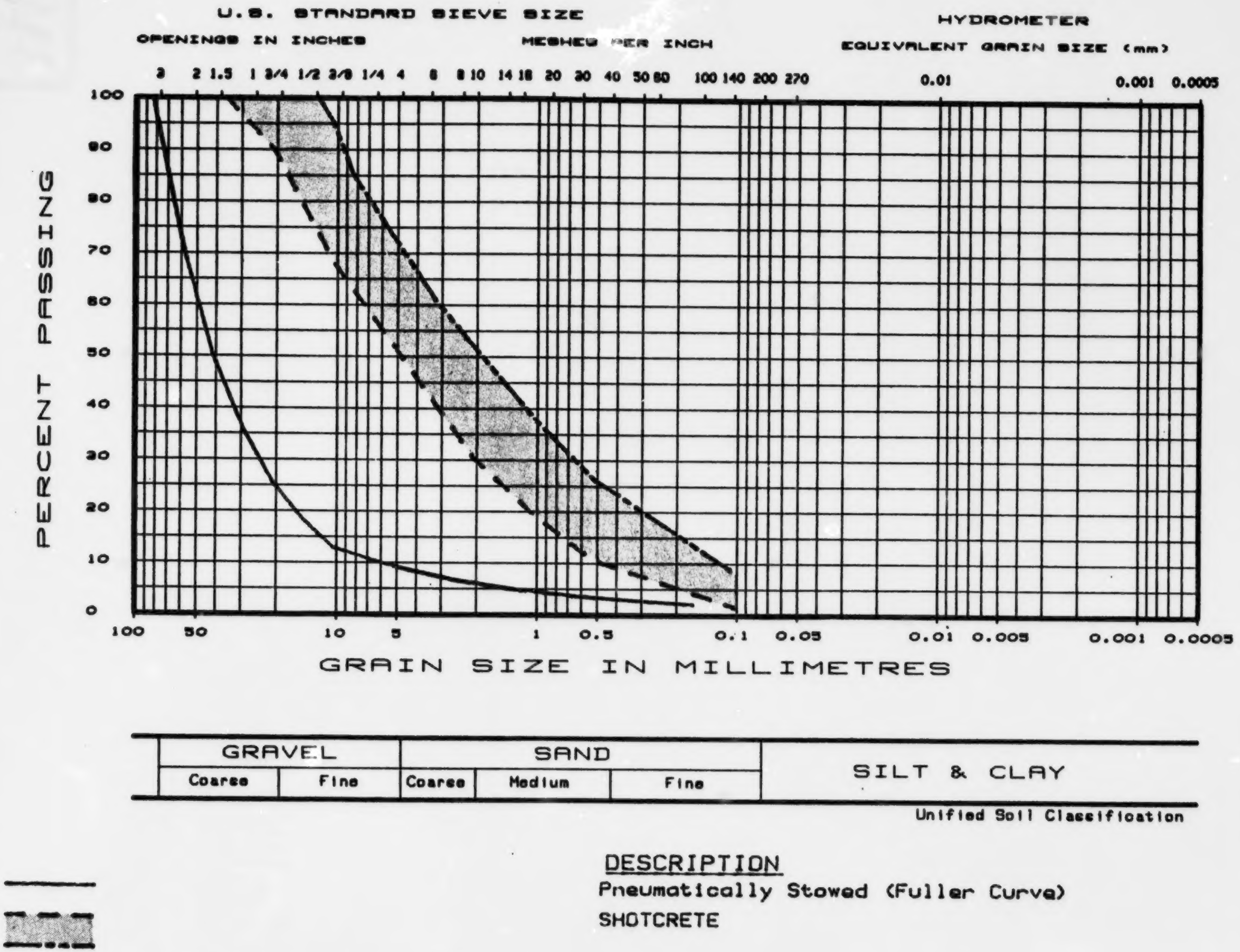

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FIGURE 3.1: Distribution Curves for Aggregate Used in Coal Mining - Shotcrete (Hoek and Brown, 1982) - Pneumatically Stowed (Bauer, 1983)

Use of Coal Refuse for Aggregate in Shotcrete

The size consist of aggregate for spray concrete work (shotcrete) has been established and is included in Figure 3.1.

Manufacture of Lightweight Aggregate from Refuse

It is reported (Wilson, 1981) that the coarse refuse from Victoria Junction Coal Preparation Plant is suitable for the production of lightweight aggregate to prepare semi-lightweight structural concretes covering a wide strength range.

Discussion

Complete Backfill of Face with Refuse

An extensive volume of coal wash plant tailings is available in the Sydney area for which the physical and chemical properties have been reported (Abbott, 1976). This report will only discuss the tailings which are available at Victoria Junction Wash Plant. The tailings at Victoria Junction are stored in two separate areas, and the following information is reported (Clyburn, 1985):

Tailings Material	Currently (1985) In-Storage (tonnes)	Annual Production (After 1987) (tonnes)
Coarse tails	6,000,000	1,000,000
Fine tails	3,000,000	200,000

The coal seams in the Sydney Coalfield are very low in ash content. The major component of the tailings is created by shale and sandstone (overlying the coal seam) which are extracted during the mining operation and sent to the surface with the coal for separation at the wash plant.

Analyses of the coarse and fine tailings material at Victoria Junction are given in Table 3.1 and 3.2, respectively, with the accompanying particle size distribution plotted in Figure 3.2.

A review of the size range of refuse would indicate that the coarse refuse is of a suitable size range for pneumatically backfilling the face. Also, a blend of coarse and fine refuse would be suitable as an aggregate for shotcrete. It is commented that these conclusions are based purely on size of particles and do not comprehend an evaluation of minerals which may be considered deleterious (especially for the shotcrete). Further testing of the mechanical strengths and chemical composition of the refuse is necessary before further conclusions can be made.

Manufacture of Light Weight Aggregate from Refuse

Though it has been commented that there is limited use of the wash plant tailings to manufacture lightweight aggregate for the mining industry, such an application for the construction industry should be considered. The Victoria Junction coarse refuse has been proven suitable for the manufacture of lightweight aggregate (Wilson, 1981). Consequently, market potential for the product should be assessed.

TABLE 3.1: Analysis of Coarse Refuse at the CBDC Victoria Junction Coal Wash Plant (Clyburn, 1985)

EMICAL ANALYSIS

ement	%
O	57.98
2	23.64
2 3	9.26
O2	0.53
O5	0.15
O	0.33
O	1.62
2	0.52
O	3.67
3	0.72
tal Det.	98.42
det. + Error	1.58

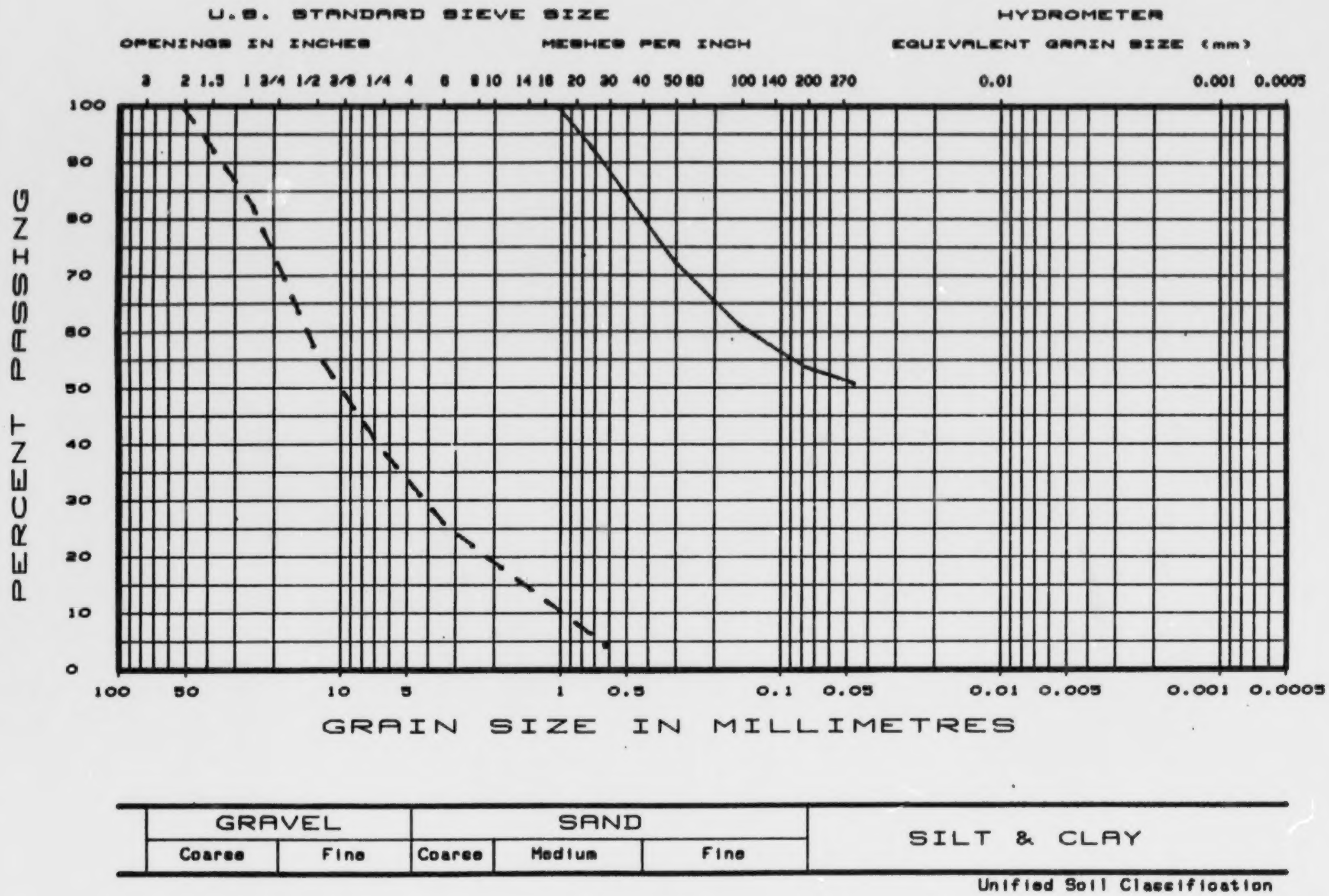
On a Dry Basis

Loss on Ignition	13.5%
Gross kJ/kg	2240
Total Moisture	4.2%
Total Sulfur	1.40%
Ash	90%

Screen Test i: mesh square openings)	Percentage Passing	Cumulative Percentage Passing
+ 50 mm	0.3	100
- 50 mm	17.2	99.3
- 24 mm	26.0	82.5
- 12.5 mm	17.4	56.5
- 6.3 mm	13.7	39.1
- 3.2 mm	21.2	25.4
- 0.6 mm	4.2	4.2

TABLE 3.2: Analysis of Fine Refuse (Thickner Underflow) at the CBDC Victoria Junction Coal Wash Plant (Stanford, 1985)

Mesh Size	Percent Passing	Cumulative Percent Passing	Ash	Sulphur
+ 24	6.9	100.0	38.79	2.24
- 24	20.3	93.1	40.83	2.02
- 48	11.6	72.8	35.80	2.29
- 100	7.4	61.2	36.40	2.56
- 200	3.0	53.8	32.01	2.12
- 325	50.8	50.8	39.14	0.89



DESCRIPTION

——— CBDC VJ Fine Refuse

– – – CBDC VJ Coarse Refuse

FIGURE 3.2: Size Distribution of Victoria Junction Wash Plant Coarse Refuse (+28 mesh) and Fine Refuse (-28 mesh) (Clyburn, 1985), (Standford, 1985)

4.0 NATURAL RESOURCES - MINE PRODUCTION AND BY-PRODUCTS

4.1 Anhydrite

Applications

Anhydrite particles when wetted (water and accelerator) will undergo an hydration reaction that will recombine the particles into a monolithic mass. The compressive strength of this material is reported (Blades, 1974) to be 20 to 30 MPa and as a result it has found use in the following applications within coal mines:

- roadway backfilling replacing wooden lagging;
- gateside strip-packs replacing wooden packs (pneumatically or hydromechanically placed);
- sprayed fireproof stopping construction replacing wooden stoppings;
- cavity filling on the face.

Requirements

One of the major considerations in the determination of the strength of the anhydrite structure is the particle size distribution of the anhydrite. As an example, the range of anhydrite products available from British Gypsum Mining Products Division for the NCB is as follows:

Particle Size	ANPAK A		ANPAK B		ANPAK C	
	%	Σ%	%	Σ%	%	Σ%
+ 7 mm	0	-	-	-	0.3	100
- 7 mm	0	-	-	-	16.1	99.7
- 5 mesh	0.1	100	-	-	11.3	83.6
- 7 mesh	trace	99.9	51.3	100	28.8	72.3
- 25 mesh	6.0	99.9	10.8	48.7	10.3	43.5
- 72 mesh	5.5	93.9	5.4	37.9	2.4	33.2
- 100 mesh	18.9	88.4	32.5	32.5	6.1	30.8
- 200 mesh	69.5	69.5	-	-	24.7	24.7

The function of each of these products is as specified by British Gypsum Mining Products Division:

ANPAK A: Suitable for Pumping
ANPAK B: Spraying Medium
ANPAK C: Pneumatic Stowing or Spraying

A size distribution curve for each of these anhydrite products is given in Figure 4.1.

Discussion

In Nova Scotia calcium sulphate may occur as anhydrite ($CaSO_4$), hemihydrate ($CaSO_4.H_2O$) or gypsum ($CaSO_4.2H_2O$). These deposits occur as interbedded layers of anhydrite and gypsum. Post depositional tectonic activity has deformed these evaporite deposits quite extensively. The complex geology in many of these deposits, created by the interbedded, folded and faulted structures, often prevent the selective mining of the economic mineral gypsum, and results in an anhydrite rich mining waste product which is frequently discarded with clays, limestones and low grade gypsum in waste dumps.

Nova Scotia producers of gypsum are listed in Table 4.1. The major product of these operations is gypsum which is marketed in the USA for wallboard manufacturing. Only a limited quantity of anhydrite is produced and marketed for blending purposes in the manufacture of ordinary portland cement. Despite the availability of anhydrite in the province, there are only limited markets for this product and it is usually left insitu when possible.

An assessment of the production capacities for anhydrite at Little Narrows Gypsum and Fundy Gypsum are that large volumes (+ 300,000 tonnes/year/operation) of pure anhydrite can be produced from existing pits, if a market existed (McMillan, 1985: Raymond, 1985). The projected cost of the anhydrite is estimated for each location to be approximately $15 f.o.b. quarry site. The Fundy Gypsum operation currently

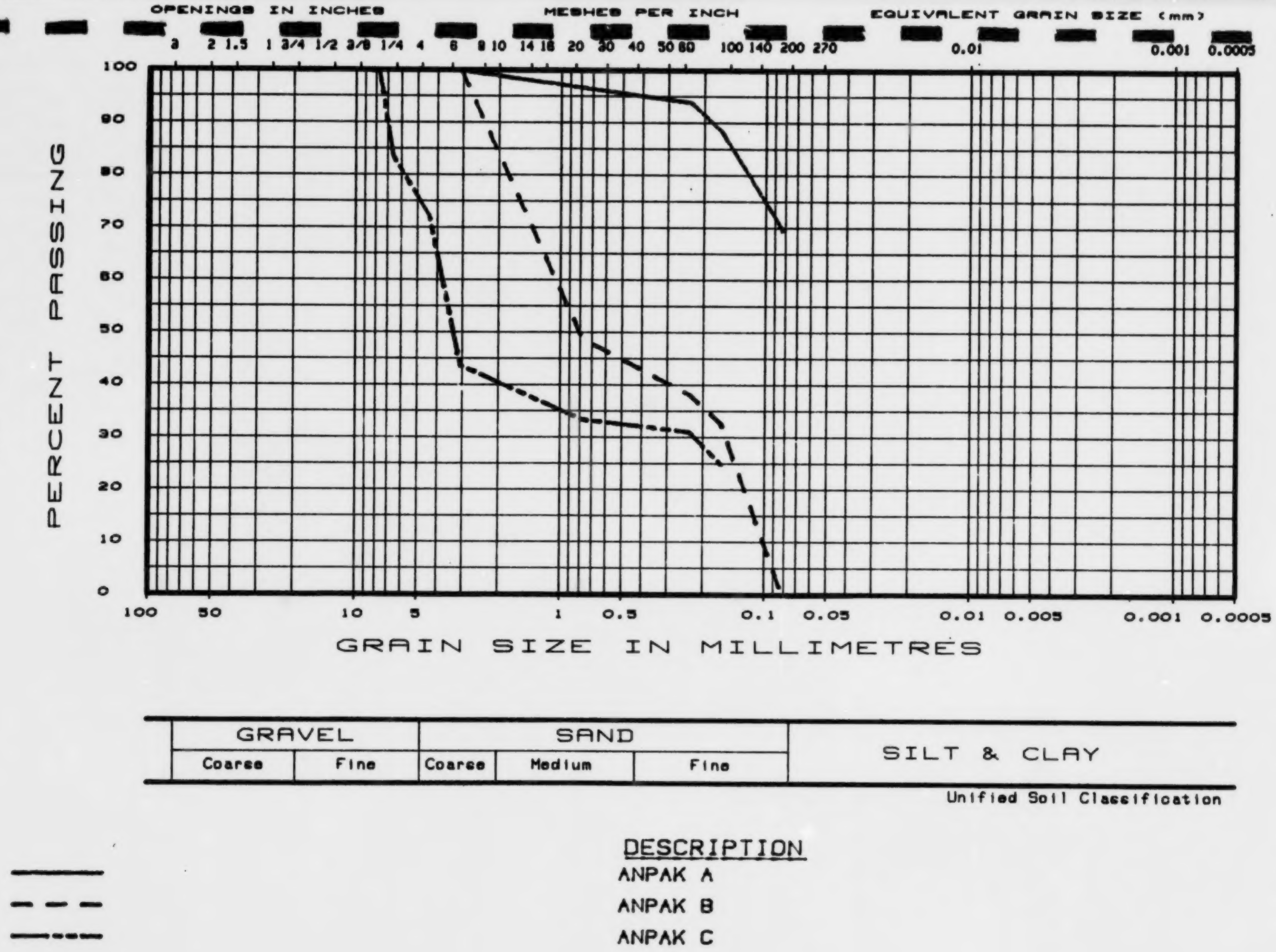


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FIGURE 4.1: Particle Size Distribution of ANPAK A, B, C
(British Gypsum Mining Products Division)

TABLE 4.1: Anhydrite Producers in Nova Scotia, 1984 Production (NSDME, 1984)

MINE/LOCATION	1984 MINE PRODUCTION	1984 WASTE	COMMENTS
	(TONNES)	(TONNES)	COMMENTS
1. Fundy Gypsum Co. Ltd. Windsor, N.S.	90,000	N/A	-
2. Little Narrows Gypsum Co. Ltd. Little Narrows, N.S.	60,000	150,000	Waste comprises limestone, sand and anhydrite fines (-20 mm)
3. National Gypsum (Canada) Ltd. Millford, N.S.	0	180,000	Waste comprises gypsum, clays, limestone, anhydrite mixture
4. Domtar Construction Materials Ltd. Windsor, N.S.	0	N/A	-
5. Georgia Pacific Corp. Port Hawkesbury, N.S.	0	N/A	40,000 t blasted in pit - no use.

incorporates a direct anhydrite crushing circuit to process anhydrite required for the processing plant. This crushing and screening facility is available to process anhydrite for coal mine usage. In addition to direct pure anhydrite, Fundy Gypsum produces a range of "sink products" which could be upgraded for use in anhydrite stowing. These products are as follows:

Particle Size (mm)	Volume (tonnes/year)	Estimated Grade (% anhydrite)
+ 50	est. 100,000	79.7
- 50 + 12.5	est. 100,000	
- 5	est. 100,000	61

In addition to the two above mentioned operations, Georgia Pacific Corporation can also produce large volumes of pure anhydrite.

Local anhydrite is of suitable grade and quality to be used in coal mines as a replacement for the wood usages previously outlined. Testing is required on the subject material to determine its chemical composition and physical strengths, following hydration, if it is to be utlized as a support material.

4.2 Gypsum and Limestone

Application

The major application of gypsum and limestone in underground coal mines is in the formulation of materials used to provide a chemical coating and sealant for mine timbers to reduce the fire hazard posed by wood.

In addition to this application, limestone is also used in the manufacture of autoclave aerated concrete blocks for gateside packwall construction while gypsum is used in a cement based cavity filling material - Aerostem (proprietary mix). A single application of a crushed limestone (-10 mm) aggregate for a pneumatically stowed gateside packwall has been identified at Mid-Continent Coal Mine Co., USA.

Discussion

The chemical coatings and mine sealants used to fireproof mine timbers are proprietary mixes in which gypsum and limestone are constituents. These products are sprayed on the wood surface in a thickness of 5 - 15 mm to provide an adequate barrier to fire. The 4.27 x 3.05 m splayed leg arch used by CBDC has a perimeter of approximately 10 m. At a spray thickness of 10 mm, the volume of spray required would be 0.1 cubic meters per meter of tunnel to fire proof "standing timber" in the mine. As these mixes are blended and prepared in factories outside the Maritimes and shipped prepackaged, there is limited chance that regional materials would be used for the preparation of these mixes for CBDC.

Autoclave areated concrete blocks are manufactured in highly specialized plants which are not available in Eastern Canada. The limited volume of this product required for coal mines would not economically justify such a plant in the area. The supply of these blocks from Central Canadian plants in Montreal and Southern Ontario would be disadvantaged by very high shipping costs. Consequently, autoclave aerated concrete blocks are not considered to be a viable option for gateside packwall construction at CBDC. Local supply of materials for this product will not be considered further in this report.

The application of crushed limestone aggregate at Mid-Continent Coal Mine, USA, was developed following undesirable results using coal refuse in a cementitious packwall construction by the Thyssen System. The unfavourable technical performance of limestone-cement material and the necessary remedial work would indicate that more desirable packwall materials are available. It is commented that Mid-Continent wanted to try an anhydrite packwall system but could not make satisfactory contractual arrangements with private railroads in the US to transport the anhydrite to the mine site.

Local suppliers of gypsum and limestone are given in Table 4.2.

TABLE 4.2: Gypsum and Limestone Producers in Nova Scotia
1984 Production
(NSDME, 1984)

MINE	LOCATION	1984 PRODUCTION (Tonnes)
GYPSUM		
1. Domtar Construction Materials Ltd.	Windsor	7,000
2. Fundy Gypsum Co. Ltd.	Windsor	780,000
3. Georgia-Pacific Corporation	Port Hawksbury	610,000
4. Little Narrows Gypsum Co. Ltd.	Little Narrows	690,000
5. National Gypsum (Canada) Ltd.	Milford	2,400,000
LIMESTONE		
1. Canada Cement Lefarge Ltd.	Brookfield	536,000
2. Mosher Limestone Ltd.	Upper Musquodoboit	149,000
3. Scotia Limestone Ltd.		NIL - 1982

4.3 Clays and Shales

Application

Clays and shales are used for the production of lightweight aggregate for use in the manufacture of lightweight aggregate concrete and concrete block. The application of lightweight aggregate has been identified in the manufacture of reinforced lightweight aggregate concrete block tested for gateside packwall construction in coal mines.

Requirements

Expanded clays are the most extensively manufactured lightweight aggregate throughout the world. The manufacturing principle has been known since 1918 and the industrial production started in 1928. Although the process differs from one factory to another, there are mainly two methods for the preparation of raw materials before burning: the dry and the wet process.

The dry process requires the reduction of the clay to a very fine dry powder. This powder is then pelletized with the addition of water in an inclined rotating dish of 2 to 4 m diameter with a flat bottom. The pellets obtained are well compacted by the centrifugal force. These pellets are then conveyed to the kiln for burning.

The wet process - (Figure 4.2) - The clay from the quarry is blended, crushed and passed through grinding mills and between rolls. Water and expanding agents are added. The fine and plastic paste of clay is then forced through perforated plates in an extrusion press. The hole diameter in the plate is chosen according to the required aggregate diameter. The extruded paste clay is then cut into pieces of the required length. The pellets obtained are dried in a rotary kiln giving them a rounded shape. The firing is done mainly in rotary kilns but sometimes grate or shaft kilns are used. The firing temperature applied is from 1150°C to 1200°C. It is very important to have a rapid rise of

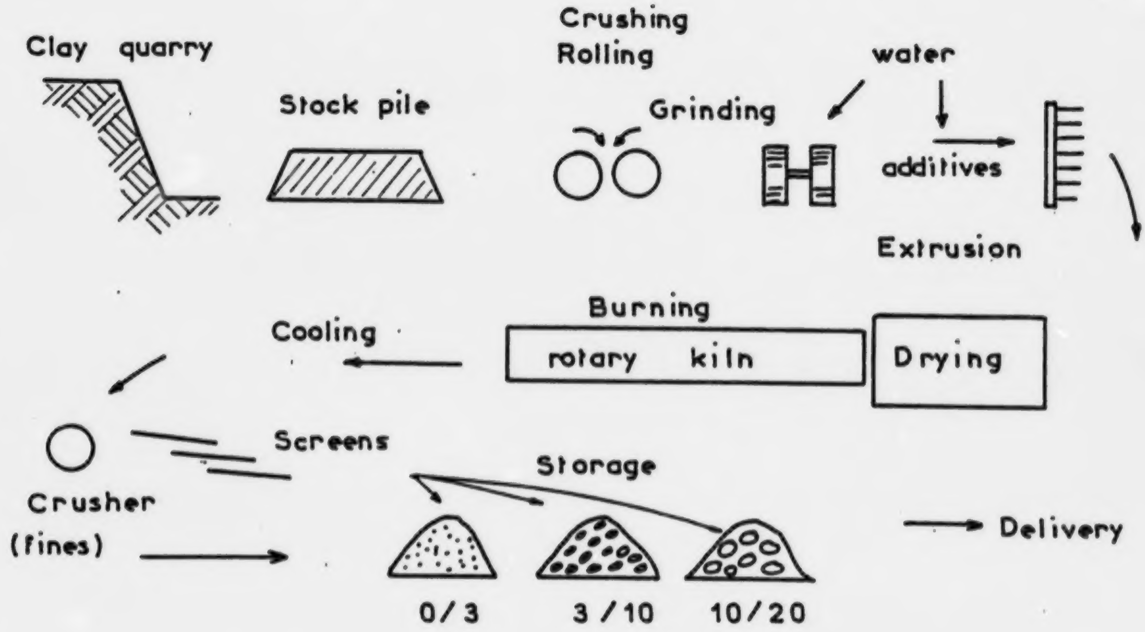
Clay quarry
Stock pile
Crushing
Rolling
Grinding
water
additives
Extrusion
Burning
rotary kiln
Drying
Cooling
Crusher
(fines)
Screens
Storage
0/3
3/10
10/20
Delivery

FIGURE 4.2: Lightweight Aggregate Production From Expanded Clay by the Wet Process (Venuat, 1980)

temperature between 700 and 1150°C to ensure the gases do not escape from the pellets. The aggregates are cooled, and screened in different particle size fractions.

The aggregates are brownish to reddish in color. The bulk densities are governed by the size fractions of the aggregate:

0-3 mm	600 - 750 kg/m^3
3-10 mm	400 - 500 kg/m^3
10-20 mm	350 - 450 kg/m^3

Some manufacturers make special high-strength lightweight aggregates used for structural reinforced concrete and pre-stressed concrete.

With similar processes, lightweight aggregates can be manufactured from slate, shale, or coal wash plant tailings. An added advantage with tailings is coal content which is useful for its calorific values in the firing process (Venuat, 1980).

Discussion

The availability of shales, and washery tailings in the Sydney area is extensive and represents a potential source of material to produce lightweight aggregate for concrete and concrete block manufacturing. A discussion on the use of lightweight aggregate is conducted in Section 3.3, outlining some possible coal mining applications as well as potential uses in the local civil engineering fields.

4.4 Aggregate

Application

The primary use for aggregate in coal mines is in concrete, which is employed in three forms; hydromechanically placed, precast into concrete blocks or sprayed. The uses for these forms include the following:

- normal weight concrete block used for construction purposes;
- shotcrete used to line a tunnel;
- shotcrete applied to wire mesh panels to form underground stoppings or construction panels;
- foamed cement for cavity backfilling;
- precast steel-fibre reinforced concrete block (Burrell "Fibrecrete" Block).

A large volume of the Portland cement supplied to modern longwall coal mines is used in the construction of gateside packwalls. In this application, hydraulically setting cements are employed with a water ratio of 85 - 90 percent, requiring no aggregate. As a result, the aggregate volume in modern longwall mines may be much less than anticipated based on the volume of OPC used.

Requirements

Specifications for aggregate materials for concrete have been developed by the CSA and ASTM. The gradation limits for coarse and fine aggregate as established by the CSA are shown in Tables 4.3 and 4.4. Restrictions on deleterious substances in fine aggregate have been established by the CSA and are included in Table 4.5

Discussion

The supply of natural aggregate is quite abundant in Nova Scotia. The Sydney area is serviced by several quarries, Table 4.6, which are within 30 km of the CBDC Coal Mines.

4.5 Mill Tailings/Mine Waste

Discussion

Within the province of Nova Scotia there are alternate supplies of material available for use as aggregate in the form of mine waste and mill tailings. These materials may require cleaning and blending and limited processing to make them useful aggregate materials.

TABLE 4.3: CSA Grading Requirements for Coarse Aggregates (CAN3-A23.1-M77, CAN3-A23.2-M77)

	Nominal Size of Aggregate mm	Total Passing Each Sieve*, Per Cent by Mass										
		112 mm	80 mm	56 mm	40 mm	28 mm	20 mm	14 mm	10 mm	5 mm	2.5 mm	1.25 mm
Group I	40—5	—	—	100	95—100	—	35—70	—	10—30	0—5	—	—
	28—5	—	—	—	100	95—100	—	30—65	—	0—10	0—5	—
	20—5	—	—	—	—	100	90—100	—	25—60	0—10	0—5	—
	14—5	—	—	—	—	—	100	90—100	45—75.	0—15	0—5	—
	10—2.5	—	—	—	—	—	—	100	85—100	10—30	0—10	0—5
Group II	80—40	100	90—100	25—60	0—15	—	0—5	—	—	—	—	—
	56—28	—	100	90—100	30—65	0—15	—	—	0—5	—	—	—
	40—20	—	—	100	90—100	25—60	0—15	—	0—5	—	—	—
	28—14	—	—	—	100	90—100	30—65	0—15	—	0—5	—	—
	20—10	—	—	—	—	100	85—100	—	0—20	0—5	—	—
	14—10	—	—	—	—	—	100	85—100	0—45	0—10	—	—
	10—5	—	—	—	—	—	—	100	85—100	0—20	0—5	—

TABLE 4.4: CSA Grading Limits for Fine Aggregate (CAN3-A23.1-M77, CAN3-A23.2-M77)

Sieve Size	Total Passing Sieve Percentage by Mass
10 mm	100
5 mm	95—100
2.5 mm	80—100
1.25 mm	50— 90
630 μm	25— 65
315 μm	10— 35
160 μm	2— 10

TABLE 4.5: CSA Limits for Deleterious Substances in Fine Aggregate (CAN3-A23.1-M77, CAN3-A23.2-M77)

Substances	Maximum Percentage by Mass of Total Sample
Clay lumps	1.0
Coal or lignite	0.5 (see also Clause 5.3.3.2)
Material finer than the 80 μm sieve	3.0*
Chert, shale, siltstones, sandstones, argillaceous limestones, friable particles, etc.	†
Reactive aggregates	(see Clause 5.3.3.3)

TABLE 4.6: Natural Aggregate Producers Within 30 km of CBDC Coal Mine Operations (NSDME, 1984)

QUARRY NAME	LOCATION	1984 PRODUCTION (TONNES)
L&R Sand & Gravel Ltd.	Sydney	35,000
Malcolm & MacDonald Co. Ltd.	Sydney River	52,000
Martell's Const. Ltd.	North Sydney	354,000
Meadows Sand and Gravel Ltd.	Sydney	91,000
Municipal Ready Mix Ltd.	Sydney	240,000
Levatte Construction Co. Ltd.	Sydney	235,000

Tables 4.7 to 4.12 and Figure 4.3 present information on the potential supply of mill tailings as an aggregate material. The sources of mill tailings include the former Yava Mines, Seabright Resources at Gays River and Rio Algom Tin Mine in East Kemptville. In addition to these supplies of mill tailings, limestone and gypsum mine waste dumps exist throughout the province, which may justify consideration as an aggregate material. A list of these potential aggregate sources is given in Table 4.13 and a location map on Figure 4.4.

As discussed in Section 4.4, the requirements for an aggregate material in local mines is very limited. The only use would be in sprayed concrete for roadway lining and precast concrete block manufacturing. It is unlikely that mill tailings and mine wastes would be used for these purposes with the abundant supply of natural aggregate in the province. The costs of processing and blending these materials to produce a suitable aggregate would tend to make this alternative economically unattractive.

TABLE 4.7: Yava Mines Tailings
(NSDME, 1984)

CHEMICAL ANALYSIS

Sample	S %	SO_4 %	Sr PPM	Pb PPM	Moisture %
1	0.44	0.80	588	3080	27.47
2	0.52	0.73	538	2300	22.46
3	0.60	0.64	455	4520	0.41

SIZE DISTRIBUTION ANALYSES

	SAMPLE		
Sieve Size	1	2	3
+100	3.7	40.0	39.6
-100 +200	16.5	29.5	23.6
-200 +326	21.6	24.4	9.0
-325	48.2	41.3	27.8

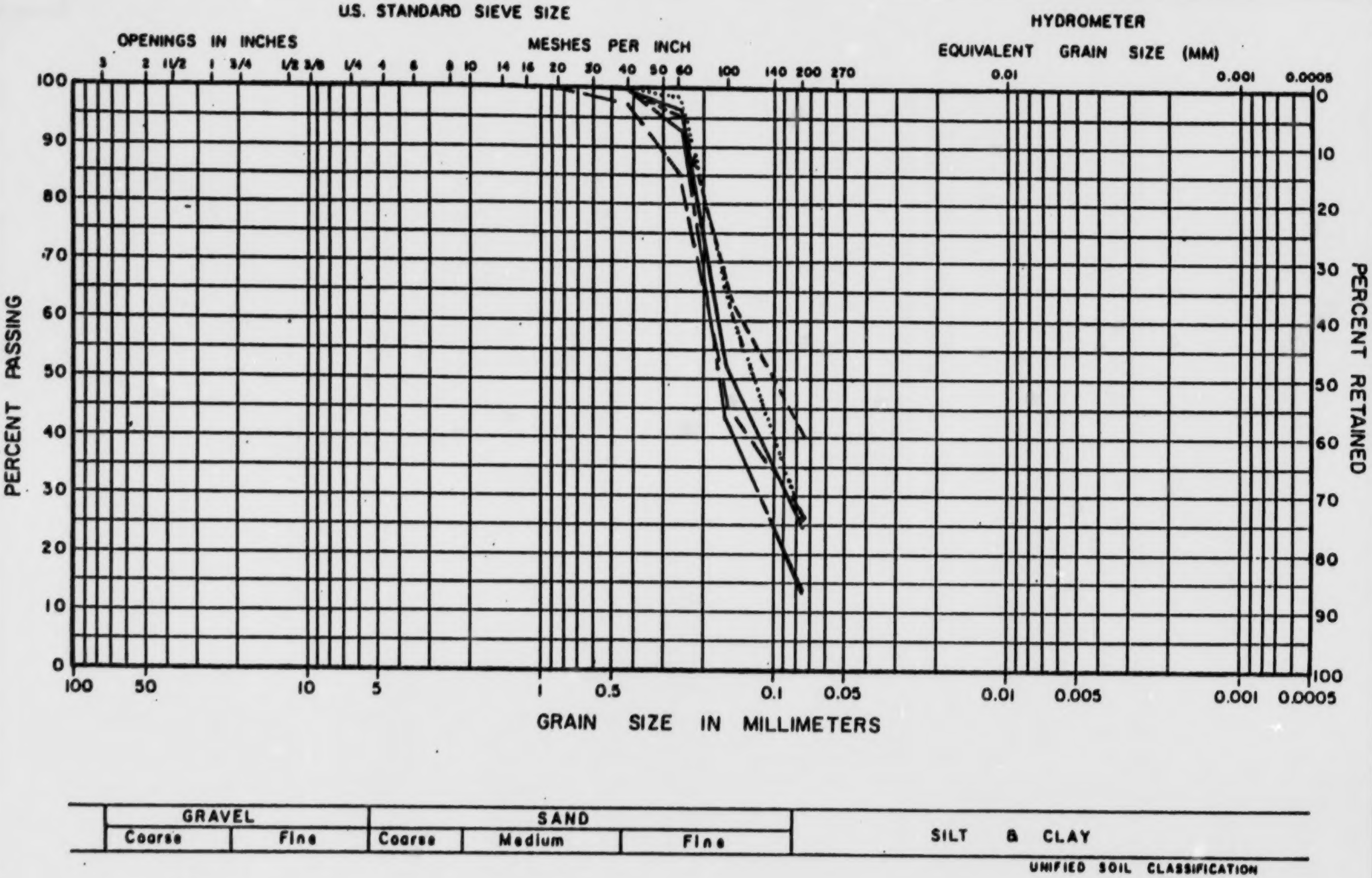

FIGURE 4.3: Yava Mine Tailings Grain Size Distribution (JWA,M1243)

TABLE 4.8: Seabright Resources (Gays River) Tailings Sieve Analysis (Rockwell, 1983)

Mesh Size Tyler	Particle Size (mm)	Slurry Tailings**				Settled Tailings*	
		% Individual		% Retained Cumulative		% Individual	% Retained Cumulative
		May/80	Apr./80	May/80	Apr./80		
+100	0.147	1.85	1.95	1.85	1.95	4.65	4.65
150	0.104	7.10	7.05	8.95	9.00	14.93	19.58
200	0.074	7.82	7.84	16.77	16.84	47.27	66.85
325	0.044	13.21	12.37	29.98	29.21	26.49	93.34
400	0.037	5.38	4.94	35.36	35.15	4.56	97.90
-400		64.64	65.85	100.00	100.00	2.11	100.00

* From Tailings Pond; Analysis by Imperial Oil Ltd., Sarnia, Ontario
** From Tailings Slurry Line Discharge: Analysis by Canada Wide Mines Ltd., Nova Scotia

TABLE 4.9: Seabright Resources (Gays River) Base Metal Distribution in Tailings Slurry (Rockwell, 1983)

Mesh Size Tyler	Particle Grain Size mm	Assays				
		Lead (wt %)		Zinc (wt %)		Copper (wt %)
		May/80	Apr/80	May/80	Apr/80	
+100	0.147	0.05	0.04	0.48	0.44	0.002
150	0.104	0.03	0.03	0.33	0.31	0.002
200	0.074	0.03	0.03	0.27	0.24	0.002
325	0.044	0.02	0.02	0.23	0.23	0.002
400	0.037	0.02	0.03	0.18	0.28	0.002
-400		0.04	0.04	0.08	0.09	0.002
	Total	0.04	0.03	0.15	0.15	0.002

TABLE 4.10: Seabright Resources (Gays River) Analysis of Settled Tailings
(N.S.R.F., G951/1, Rockwell, 1983)

ELEMENT	ppm.	ELEMENT	ppm.	ELEMENT	wt.%
Ag	1.50	Na	13.00	Al	0.27
As	<0.50	Ni	13.00	Pb	0.04
B	72.00	Sb	27.00	Fe	0.81
Be	0.25	Se	0.09	Zn	0.45
Cd	8.00	V	17.30	SiO_2	15.20
Cl^-	<10.00	K^x	45.00	Mg	9.20
Cr	5.50	P^x	<3.00	Ca	16.70
Cu	11.00		ppb	C^{xx}	10.16
Mo	0.50	Hg	<10.00	SO_4	0.38
C^{xxx}	140.00				

pH = 8.10

($CaCO_3$ = 41.75%; $MgCO_3$ = 32.20%; C.C.E. = 80.1%)^{xxxx}

^{x}Total, ^{xx}Organic, ^{xxx}Inorganic, ^{xxxx}Calculated

TABLE 4.11: Rio Algom Mines, East Kemptville Project
Gradations of Tailings Material*
(NSDME)

Sieve Size		Percent Passing By Weight		
US Standard Mesh	Microns	Coarse	Slimes	Flotation
#20	850	100	100	100
#40	425	73	100	100
#60	250	38	100	100
#100	150	19	99	94
#200	75	9	95	76
#270	53	5	87	51
#400	38	2	75	41

* Environemental Applications Group 1983.

TABLE 4.12: Rio Algom Mines, East Kemptville Characteristics of Tailings Material (NSDME)

	TAILINGS		
Item	Coarse	Slimes	Flotation
Production Rate (tonnes/hr)	314	98	2.2
Percent of Production	75%	24.5%	0.5%
Pulp Density (Percent Solids by Weight)	45%	4.5%	27%
Specific Gravity	2.72	2.80	3.55
Total Weight (tonnes x 10^6)	45.4	14.3	0.35
Projected In-place Dry Unit Weight (tonnes/m^3)	1.44	1.36	1.60
Projected In-place Total Volume (m^3 x 10^6)	31.5	10.5	0.22
Transport Water Volume (tonnes/hr)	385	2055	5.9
Acid Production Potential	Acid Consumer	Marginal Acid Producer	Acid Producer

TABLE 4.13: Mine Waste and Mill Tailings in Nova Scotia (NSDME, 1984)

Mine	Location	Mill Tailings	Mine Waste (tonnes/year)
Yava Mines	Cape Breton	--	--
Rio Algom	East Kemptville	9,000 tonnes/day	--
Seabright Resources	Gays River	667,000 tonnes*	--
Little Narrows Gypsum	Little Narrows	--	150,000
National Gypsum	Milford	--	100,000

* Implaced from Canada Wide Mines lead-zinc concentrator

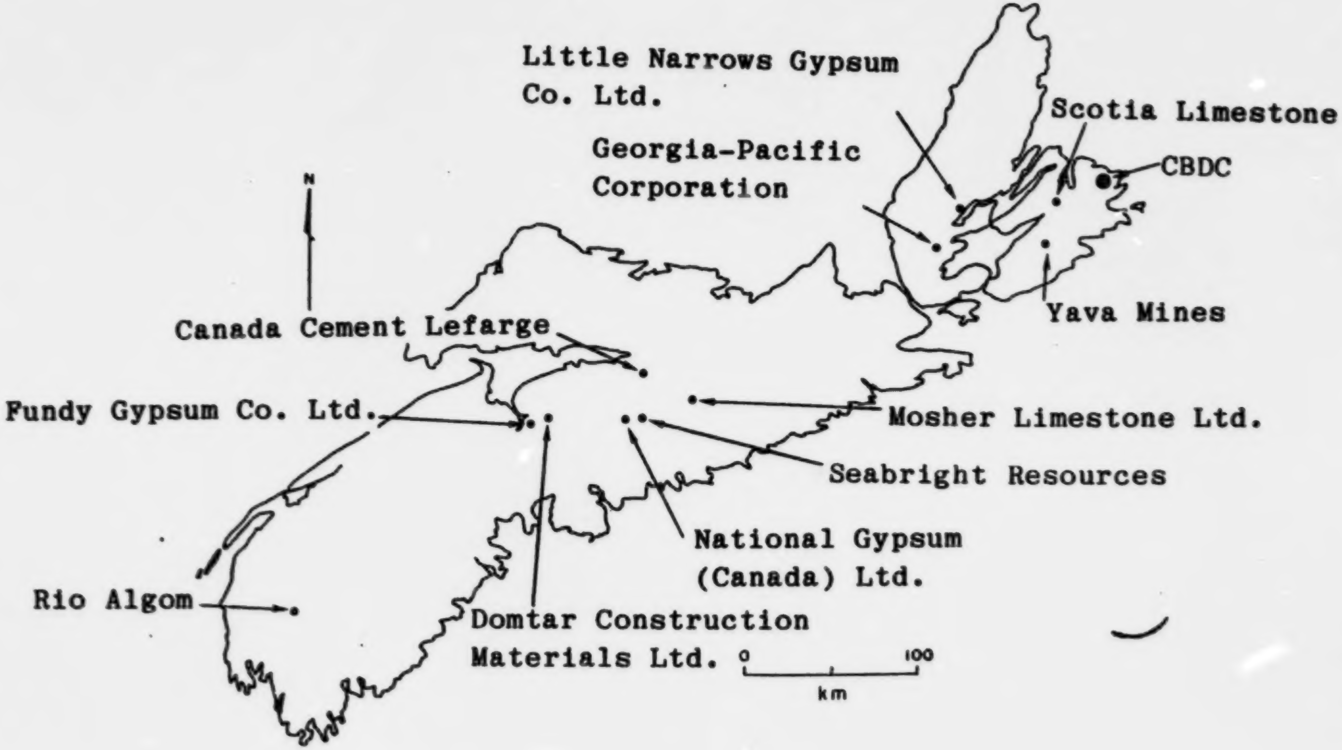
Little Narrows Gypsum
Co. Ltd.
Georgia-Pacific
Corporation
Scotia Limestone
CBDC
Yava Mines
N
Canada Cement Lefarge
Fundy Gypsum Co. Ltd.
Mosher Limestone Ltd.
Seabright Resources
National Gypsum
(Canada) Ltd.
Rio Algom
Domtar Construction
Materials Ltd.
0
100
km

FIGURE 4.4: Location Map of Various Mines and Mill Tailings in Nova Scotia (NSDME)

5.0 INDUSTRIAL PROCESS BY-PRODUCTS

5.1 Fly Ash

Applications

Fly ash, by-product from coal-fired power generating plants, possesses the ability to react chemically with calcium hydroxide (lime) at ordinary temperatures to form compounds which demonstrate cementitious properties. This reaction is known as a "pozzolanic reaction", (ASTM C 595). In addition to its use as a pozzolanic substitute for OPC in concrete, fly ash has also been agglomerated to form an aggregate used in concrete.

Fly ash has been used in underground coal mines in the following applications:

- a pozzolanic substitute in a cementitious material for complete roadway backfilling replacing wooden lagging;
- an admixture in a cementitious material for grout envelopes replacing wooden lagging;
- a component in the manufacture of autoclave aerated concrete block which can be used to replace both wooden gateside packs and wood as a construction material for stoppings, isolation areas, etc.;
- a cementitious material "Flashpack" used to produce monolithic packwalls replacing wooden gateside packs;
- an admixture in a foamed cement used for cavity filling replacing open wooden chocks;
- a component in a material used for complete backfilling of the face.

Requirements for Fly Ash as a Pozzolanic Material

The ASTM Standard Specification for Mineral Admixtures (C618) states that there are two classes of fly ash:

Class F (low calcium) - fly ash must have a minimum of 70% (silica + alumina + iron oxides);
Class C (high calcium) - fly ash must have a minimum of 50% (silica + alumina + iron oxides)

The major difference in these fly ash materials is the amount of calcium, in the form of analytical CaO. It is possible to catagorize fly ash based on the type of coal used in the power plant thermal process:

Type	Class	CaO Range	Coal used in Plant
Low Calcium	Class F	5%	anthracite and bituminous coals
High Calcium	Class C	15-35%	lignite and subbituminous coal

Table 5.1 presents specific information on these fly ash materials based on their pozzolanic and cementitious properties.

Low calcium (Class F) fly ash is considered a normal pozzolanic substitute for OPC in concrete.

High calcium (Class C) fly ash is a more reactive pozzolanic substance than the low calcium fly ash, plus it also contains minerals which react readily to form cementitious calcium aluminates and sulfoaluminate hydrates (traditional to OPC hydration reactions). Consequently, the high calcium fly ash represents the more desirable substitute for OPC in concrete.

Requirements of Fly Ash as an Aggregate

Industrial processes have been developed to make both a light weight and normal weight aggregate from fly ash for use in concrete as well as an aggregate for road bed construction. The process has been described (Bijen, 1980) as having two steps; an agglomeration process followed by a bonding process. Numerous techniques are used to accomplish these processes:

Agglomeration Processes:

- agitation method (disc, drum, cone agglomeration);
- pressure method (piston presses, roll briquetting, screw extrusion, pellet mills);
- melting (pelletize melt using water),
  (air cool melt and subsequently crush).

Table 5.1: Classification, Composition and Particle Characteristics of Fly Ash as a Cementitious and Pozzolanic By-Products for Concrete (Mehta, 1979)

CLASSIFICATION	CHEMICAL AND MINERALOGICAL COMPOSITION	PARTICLE CHARACTERISTICS
1. Cementitious & Pozzolanic		
High-calcium fly ash:	Mostly silicate glass containing mainly calcium, magnesium, aluminum, and alkalies. A small quantity of crystalline matter may be present. Unburnt carbon is usually less than 2%	Powder corresponding to 10-15% particles larger than 45 mm (usually 300-400 m^2/kg Blaine). Most particles are solid spheres of less than 20 mm diameter. Particle surface is generally smooth but not as clean as in low-calcium fly ashes.
2. Highly Active Pozzolans		
NIL	-	-
3. Normal Pozzolans		
Low-calcium fly ash:	Mostly silicate glass containing aluminum, iron and alkalies. The small quantity of crystalline matter present consists generally of quartz, mullite, sillimanite, hematite, and magnetite. Unburnt carbon is usually less than 5%, but may be as high as 10%.	Powder corresponding to 15-30% particles larger than 45 um (usually 200-300 m^2/kg Blaine). Most particles are solid spheres of average 20 mm diameter. Cenospheres and plerospheres may also be present. Particles have a smooth texture
4. Weak Pozzolans		
NIL	-	-

Bonding Processes:

- sintering (material bridge bonding);
- hydrothermal (matrix bonding under pressurized steam);
- cold bonding (matrix bonding at ambient temperatures).

The literature does not indicate any special requirements for the use of fly ash as an aggregate and attributes the properties of the synthetic aggregate to the method of bonding by example:

- sintered fly ash aggregate is a heavy-lightweight type while the hydrothermal and cold bonded aggregate are light-ordinary weight.
- the freeze-thaw properties of the hydrothermally bonded aggregate is inferior to the sintered or cold bonded aggregate.

Discussion of Fly Ash as a Pozzolanic Substitute

The coal fired power plants in Nova Scotia operate using high volatile bituminuous. A coal which would indicate that a Class F (low calcium) fly ash would be produced. This fact is supported by a chemical analysis on the fly ash from the Lingan Power Station (performed by the Nova Scotia Research Foundation) that shows:

Fly Ash Composition	%	Total %	Criteria for Class F	Class
CaO	0.46	0.46	5%	F
Fe_2O_3	22.22	88.81	70%	F
SiO_2	43.14			
Al_2O_3	23.45			

Mechanical testing of concrete in which fly ash was used as a pozzolanic substitute for OPC was conducted for the Nova Scotia Power Corporation. These tests showed that the fly ash materials in Nova Scotia are suitable for use in concrete. A 20% replacement for OPC in concrete mix will not alter the compressive strength of the concrete (Bell, 1985) significantly, Table 5.2, Figure 5.1. Current work is being performed on contract to Cape Breton Coal Research Laboratories, CANMET, to investigate the properties of fly ash from the Lingan Power Generating Station for use in a "Flashpack" monolithic packwall system.

TABLE 5.2: Lingan Fly Ash Concrete Test Results
Mix Design Data
(Bell, 1985)

SAMPLE DATE: 1983-08-23 SAMPLE NO. 83-E0800

MIX INGREDIENTS (kg/m³)	CONTROL MIX	TEST MIX
Portland Cement	355	284
Fly Ash:		
- Total	-	85
- 'Cementitious' Component	-	71
Sand	835	821
3/4" Gravel	1,045	1,045
Total Water	170	160
Air Entraining Agent (ml/m³)	210	178
MIX PROPERTIES		
Fly Ash/Replacement (% -Nominal)	-	20
Air Content, %	6.2	6.0
Slump (mm)	70	70
Water/Cementitious Material Ratio	0.48	0.455
Unit Weight (kg/m³)	2,329	2,345

MIX COMPRESSIVE STRENGTHS (MPa)

DAYS	CONTROL MIX	TEST MIX
3	21.3	18.4
7	24.9	23.2
14	-	-
21	-	-
28	29.9	30.0
60	-	-
90	-	-
120	-	-
200	-	-

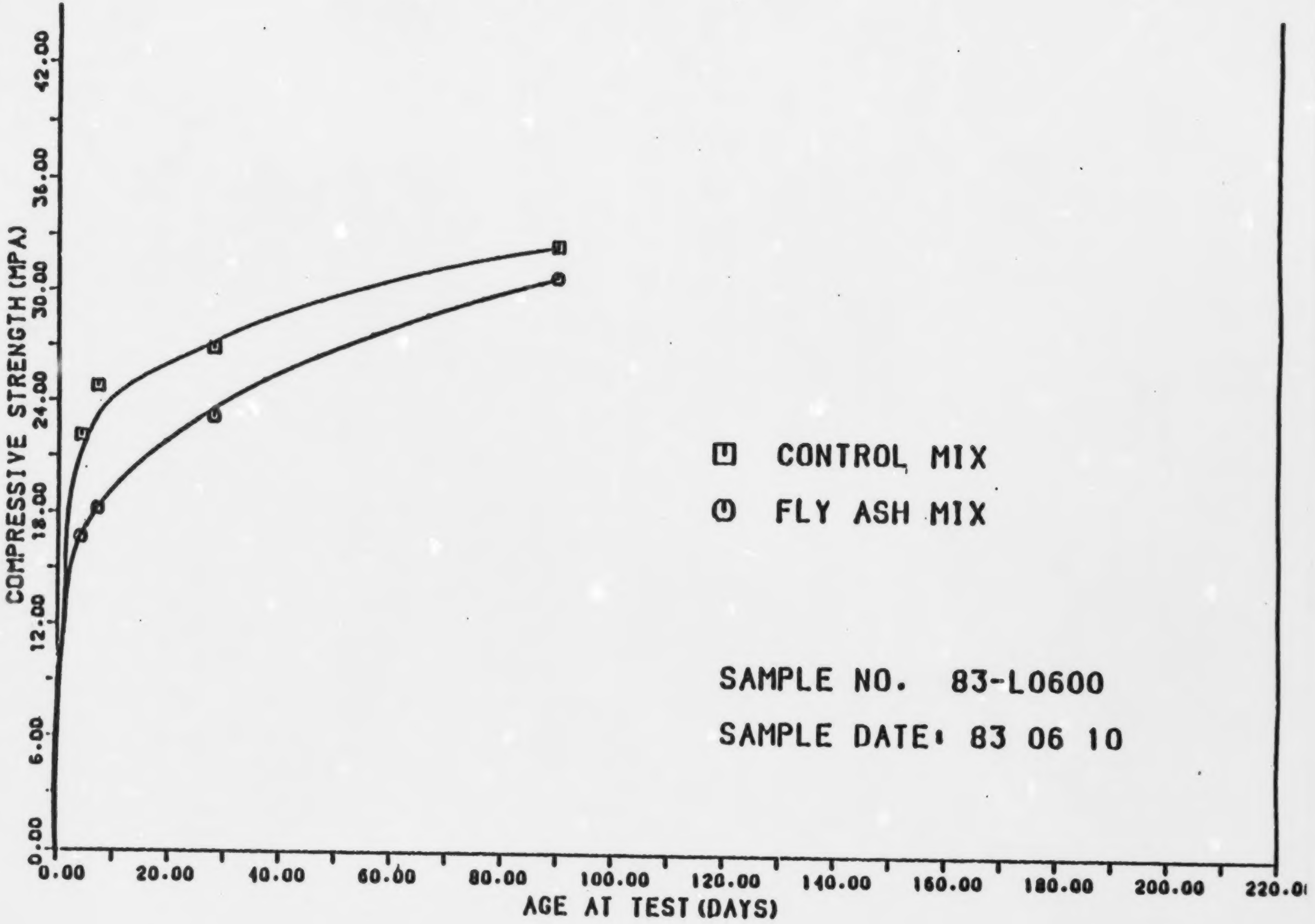

FIGURE 5.1: Lingan Fly Ash - Concrete Strength
(Bell, 1985)

Discussion of Fly Ash as an Aggregate

There is no indication that work has been done to investigate the use of Nova Scotia fly ash for synthetic aggregate production.

Discussion of Fly Ash Disposal Problem

The production of fly ash in Nova Scotia currently occurs at the Lingan Power Station; however, the future operation of the Point Tupper plant will add to the current fly ash disposal problem in the province. The annual production of fly ash is reported (Bell, 1985) as:

150,000 tons/year - Lingan
308,000 tons/year - Point Tupper (1997)

During the planned 40 year life of the Point Tupper Plant, a disposal area of 50 hectares will be required for fly ash disposal unless an industrial use of this material is found (Bell, 1985).

5.2 Metallurgical Slags

Applications

Metallurgical slags (Blast Furnace, Steel Slags, and Non-Ferrous Slags) are potentially useful in the production of a pozzolanic substitute for OPC in concrete and in the production of synthetic aggregates.

The applicaiton of metallurgical slags in coal mines has been identified in the following capacities:

- production of autoclave aerated concrete block
- production of foamed slag aggregate block for gateside packwall construction (never put into industrial operation)

There is no indication in the literature that slags have been used as a pozzalonic substitute in cements employed in underground coal mines.

Requirements for Pozzolanic Substitute for OPC

The metallurgical slags which have been investigated as a pozzolanic substitute for OPC include:

- Blast furnace slags;
- Steel slags;
- Non-ferrous slags (lead slags).

The technology for each of these materials will be discussed briefly as regional supplies of these slags are available.

Blast Furnace Slag

In the production of pig iron in a blast furnace, if the slag is cooled slowly in air, the chemical components of slag are usually present in the form of crystalline melilites which do not react with water at ordinary temperature. If ground to very fine particles, the material will be weakly cementitious and pozzolanic. However, when the liquid slag is rapidly quenched from high temperature (1400-1500°), either by water or a combinaion of water and air, most of the lime, magnesia, silica, and alumina can be held in a non-crystalline or glassy state. The water-quenched product is called granulated slag due to the sand-size particles, whereas the slag quenched by water and air is in the form of pellets, and is called pelletized slag. Normally the former contains more glass; however, both products when ground to 400 to 600 m^2/kg Blaine surface area are capable of developing satisfactory cementitious and pozzolanic properties (Mehta, 1979).

Open-Hearth Slag

Steel slags are a byproduct of the conversion of pig iron to steel. Basic oxygen furnace, open-hearth, and electric-arc furnace are used for this purpose. The slag is similar in chemical composition to iron blast furnace slag except that it usually contains a larger proportion of iron oxide and smaller amounts of silica and alumina. As may be expected, steel slag cooled slowly in air is virtually inert. However, reactive slag for use as a cementitious and pozzolanic admixture for concrete can be produced by water granulation (Mehta, 1979).

Non-Ferrous Slags (Lead Slag)

In the smelting process of lead, the slag product is traditionally high in CaO, ranging 10-20%. When these slags are water quenched, pozzolanic properties as well as cementitious properties are evident (Mehta, 1979).

A summary of the characteristics of slags as a cementitious and pozzolanic material in cement is given in Table 5.3.

Requirements for Production of a Synthetic Aggregate

Blast furnace slags are used in the production of two lightweight aggregates for concrete:

- slag pellets;
- foamed slag aggregate

Slag Pellets

Slag pellets (called Galex) are manufactured from the molten slag coming from blast furnaces. Several injections of water followed by a mechanical dispersion with a rotary drum (Figure 5.2) are used in this process. The pellets thus formed are quickly cooled in the air and a vitreous external shell is formed. The pellets fall back on an inclined ground covered with grates. The water is eliminated by the heat of the pellets or through the grate. The pellets are then screened into 3 different size fractions, for example 0-3 mm, 3-8 mm, 8-15 mm. The 0-3 mm sand is vitreous and can be used for making cement. A gradation of the slag pellets is provided during the projectile motion through the air. The small, dense sands collect near the rotary drum while the coarse lightweight pellets are projected a greater distance from the rotary drum. The particles bigger then 3 mm are lightweight aggregates with vitrified external skin and a more or less crystallized internal part. The bulk density, according to the size, is the following (Venuat, 1980):

TABLE 5.3: Classification, Compsition and Particle Characteristis of Metallurgical Slags as a Cementitious and Pozzolanic By-Products for Concrete (Mehta, 1979)

CLASSIFICATION	CHEMICAL AND MINERALOGICAL COMPOSITION	PARTICLE CHARACTERISTICS
1. Cementitious & Pozzolanic		
Granulated Blast Furnace Slag	Mostly silicate glass containing mainly calcium, magnesium, aluminum, and silica. Crystalline compounds of melilite group may be present in small quantity.	Unprocessed material is of sand size and contains 10 to 15% moisture. Before use it is dried and ground to particles less than 45 um (usually about 500 m^2/kg Blaine). Particles have rough texture.
2. Highly Active Pozzolans		
NIL	-	-
3. Normal Pozzolans		
NIL	-	-
4. Weak Pozzolans		
Slowly-cooled slag,	Consists essentially of crystalline silicate minerals, and only a small amount of non-crystalline matter.	The materials must be pulverized to very fine particle size in order to develop some pozzolanic activity. Ground particles are rough in texture.

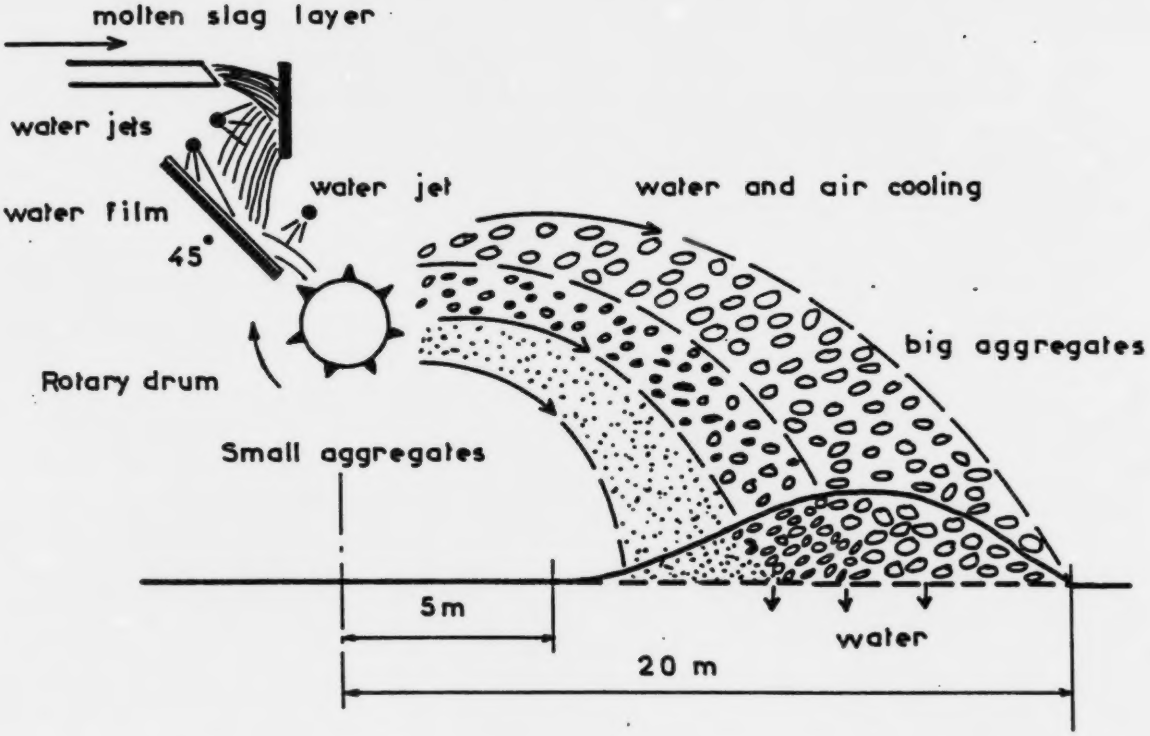
molten slag layer
water jets
water film
45°
water jet
water and air cooling
big aggregates
Rotary drum
Small aggregates
5 m
water
20 m

FIGURE 5.2: Manufacture of Slag Pellets (Galex) Venuat, 1980)

1000 kg/m^3 for the 0-3 mm;
800 kg/m^3 for the 3-8 mm;
650 kg/m^3 for the 3-12 mm.

Foamed Slag Aggregate

The principal of making foamed slag is as follows. Molten slag is run into a basin whose bottom is formed by a layer of wetted no-fines concrete. Under this is installed a system of water pipes by means of which, at the instant when the slag runs into the basin a large number of water jets are injected into the slag (for example 1 m^3 of water per ton of slag). Alternatively, steam and compressed air may be injected. The steam formed in the slag or injected into it produces numerous bubbles which cause the slag to expand so that, on cooling it becomes an artificial rock like material with a cellular structure. The foamed slag is more or less dark grey in color with rough surface texture internally porous and honeycombed. It is picked up by grabs, stockpiled, crushed and screened to give different particle sizes. It is an economical process because the initial material does not have to be heated. The aggregate obtained in this way is completely inert and stable (Venaut, 1980).

In addition to using blast furnace slags to produce lightweight aggregate; it is also used as a normal weight aggregate in concrete. Either air-cooled or granulated blast furnace slags, when crushed and sized, can be used as a coarse or fine aggregate in concrete replacing natural aggregate. It is noted that the air-cooled blast furnace slag aggregate is reported to require increased pumping pressures over natural aggregate concretes, while granulated blast furnace slag aggregate does not affect pumping pressures (Kajami, 1979).

One specific use of finely ground blast furnace slags is in the manufacture of autoclave aerated concrete block. In this capacity, the fine sized slag aggregate is in competition with other highly silicious fine aggregates such as pulverized fly ash and sand.

Discussion

Pozzolanic Substitute

Though it has not been identified as a current use for slags in coal mines, the proximity of the Sydney Steel Corp (SYSCO) operations to the CBDC coal mines makes the potential use of these slags as a pozzolanic material worth consideration.

A chemical analysis of these metallurgical slags, as provided by Sydney Steel Corporation, are included in Table 5.4. At the current time all these slags are air cooled and therefore would not be a good pozzolanic material. If these slags are to be used as a substitute for OPC in concrete, water or water and air quenching facilities will have to be installed at SYSCO.

Production volumes of slags at SYSCO are:

Blast Furnace Slag	227 tonnes/day;
Open Hearth Slags	91 tonnes/day;

and represent a large source of a potentially useful product.

Brunswick Mining and Smelting (BM&S) in Belledune, New Brunswick, operates a lead smelter in which the slag is water quenched. Current work by BM&S on the use of the lead slag as a pozzolanic and cementitious product is being investigated for use in a cemented backfill for the BM&S mining operations at Bathurst, New Brunswick. Information on these lead slags are presented in Table 5.5

The lead slag option for use in CBDC coal mines will not be discussed at length because supply of a better slag material for admixtures in concrete is readily available from SYSCO at a much lower transportation cost (if a water quenching facility was installed).

TABLE 5.4: Properties of Sysco Slags
(McCarron, 1985)

ANALYSIS	BLAST FURNACE SLAG	OPEN HEARTH SLAG	
		FLUSH SLAG	TAP SLAG
SiO_2	25.0 - 40.0	20.0 - 31.0	9.0 - 20.0
MgO	10.0 - 18.0	4.0 - 10.0	10.0 - 23.0
CaO	30.0 - 50.0	9.0 - 25.0	25.0 - 43.0
Al_2O_3	7.0 - 15.0	-	-
S	1.4 - 2.4	-	-
MnO	.20 - .50	13.0 - 21.0	5.0 - 13.0
TiO_2	.30 - .50	-	-
Fe	.40 - 1.0	13.0 - 28.0	28.0 - 44.0
Na	.15 - .60	-	-
K	.05 - .40	-	-
FeO	-	35.0 - 55.0	15.0 - 35.0
P_2O_5	-	1.20 - 2.50	0.87 - 1.20

TABLE 5.5: Characteristics of Brunswick Mining and Smelting Slag

ANNUAL PRODUCTION RATES OF GRANULATED SLAGS

1982	174394 MT
1983	165100 MT
1984	160900 MT

NOTE: Present stockpile of granulated slag contains all production from 1966 to 1985 inclusive.

TYPICAL ASSAY

Zn	Pb	FeO	Al_2O_3	S	Cu	Bi	As gm/Mt
7.70	3.53	41.88	1.98	1.38	.15	0.14	10.3

SiO_2	CaO	As	Sb	Cd
22.83	16.12	.26	.052	.014

SIZE ANALYSIS - 1981

Mesh No.	Size (Inches)	Size (cm)	Percent Retained	Cumulative Percent
24	.0278	.071	3.8	3.8
48	.0117	.029	60.9	64.7
65	.0083	.021	17.4	82.1
100	.0059	.015	9.5	91.6
200	.0029	.007	6.4	98.0
325	.0017	.004	1.4	99.4

Synthetic Aggregate

The use of air-cooled blast furnace slags at SYSCO to produce normal weight aggregate for concrete is highly unlikely as there is an excellent supply of natural aggregate in the area. Unless a greater emphasis is placed on the effective use of resources (obviously slags are a resource) limited interest will be demonstrated in their use.

The production of autoclave aerated concrete block is conducted on a mass production basis of standardized block units in an atmospherically controlled factory with specialized moulds, cutting machines and autoclaves. The demand for such a block, even if it was adopted at CBDC for gateside packwall construction, would not be sufficient to warrant the capital investment required for such a factory. It is therefore concluded that a finely ground slag aggregate used in the production of autoclave aerated concrete block for CBDC is not an economic reality. Also, the performance of the autoclave aerated concrete block packwall is very similar to the performance of the monolithic pumped packwall which can be constructed with much less labour and lower material costs than the autoclave aerated concrete block packwall.

6.0 MANUFACTURED MATERIALS

6.1 Ordinary Portland Cement

Applications

Ordinary Portland cement is the binding agent used in a large number of products that can be employed to reduce the risk of wood fires in underground coal mines. These uses are identified in Table 2.1 and include the following:

- cement based mine sealant which is sprayed on mine timbers to provide a fire-proof surface and thereby isolate the wood from any ignition source;
- manufacture of concrete blocks that can be employed as a construction material for stoppings, isolation rooms, etc. and as a chock member for packwall construction. These blocks include:
  - normal weight concrete block,
  - lightweight aggregate concrete block,
  - autoclave aerated concrete block,
  - fibre reinforced concrete block;
- precast lagging boards;
- sprayed concrete (shotcrete) which is used to generate a support shell in a mine roadway thus replacing wooden lagging or can be sprayed on a steel mesh to form a panel suitable for constructing mine stoppings, isolated rooms, etc. and therefore replace the use of wood as a construction material;
- cement-based hydraulically placed backfill materials for complete or partial roadway backfilling materials;
- special high water-ratio cements for use in the monolithic pumped pack systems;
- a major component in most of the cementitious cavity filling products;
- for grouts used in strata reinforcement systems.

Discussion

OPC is manufactured in Nova Scotia by Canada Cement Lafarge Ltd. in Brookfield. In addition to this supply, OPC is also imported into the province in bulk tankers.

Cement based materials can be designed to satisfy a wide range of applications. This is evidenced by the many different cement products used in coal mines; sprayed concrete, foamed concrete, high water ratio cement mixes for monolithic packs, precast concrete blocks, etc.

Throughout the previous sections of Phase II - Part II of this report, discussion of substitute materials (slags, fly ash) for OPC in concrete was conducted to emphasize the potential use of locally available materials. Also, the use of local aggregate for concrete could be implemented (where it is required).

6.2 Sodium Silicate and Miscellaneous Chemicals

It is recognized that the manufacture of these chemicals is not performed within Nova Scotia; however, their use has been included as regional suppliers of these products would be able to provide them.

6.3 Steel

Application

In addition to the use of steel arch roadway support members, steel has been identified as being used in several other applications:

- steel mesh lagging (extensible mats, back-lagging mats);
- rock bolts, dowels;
- steel fibres for concrete/grout reinforcement.

Discussion

Current production at Sydney Steel Corporation is utilized to manufacture steel rails. Consideration of the extension of this product line to manufacture steel-wire or steel dowels (re-bar) for the mining industry is beyond the capacity of this report.

However, the development of the production capacity to manufacture steel mesh lagging products using imported wire is quite possible if the technology is adopted by CBDC. It is commented that the efficient, low cost production of wire mesh panels is done in West Germany on highly automated machines. Such technology if developed in Cape Breton, could easily supply a large part of the North American demand for this product as there are currently no manufacturers in Canada or the U.S.A. Also, the local production of rock bolts and steel dowels could likely be satisfied by a regional foundry.

6.4 Fabric Manufacturing

Fabric materials are used within the coal mining industry for several applications:

- brattice cloth;
- ventilation duct;
- grout envelopes;
- pump packing bags;
- roadway backfilling covering sheets;
- inflatables for cavity filling.

The local textile industry has been used to prepare packhole bags for the testing program in monolithic pump packs. Obviously further development of this industry could be assisted by the adoption of the above technologies using textile material.

7.0 WOOD REPLACEMENT PRIORITIES

An evaluation of the necessity to replace wood in underground coal mines must be based on a criteria that reflects the relative risks the various wood usages represent to the mine personnel and plant. The fault tree risk assessment model developed in Phase I of this report outlines a conceptual, descriptive model which can be used to formulate a logical approach for this analysis. As a descriptive model it is not designed to calculate a "bottom-line" risk assessment value. This model can be used in such a capacity only if an extensive volume of risk probability data is generated and input to the model. In view of the large investment in time and money which is required to accomplish this goal, it is unlikely that a quantification of the descriptive model will be available in the short term to use in the assessement of wood replacemnt priorities.

To assess the need for the replacement of specific wood usages in CBDC coal mines, a risk index model is proposed. It is emphasized that this risk index model is not designed to determine the absolute risk of a fire in the mine. The sole intent is to provide a relative scale of fire risk associated with each of the wood applications discussed in Phase II - Part I of this report. The "FIRE RISK INDEX" (FRI) values generated from this model will be used to assess the relative risk associated with each wood usage at CBDC coal mines. No standardization of the range of FRI values has been attempted and as a result the order of magnitude of relative risk values is uncertain.

7.1 Description of "FIRE RISK INDEX" Model

The "FIRE RISK INDEX" (FRI) model subdivides the mine into functional areas (working panels, main slopes, development areas and abandoned areas). Each of these areas is further subdivided into more discrete functional sub-areas. This breakdown of the mine plant is adopted from the fault tree model; however, expansion to some functional sub-areas have been made for the FRI model.

The determination of the FRI values is based on the presence of fuel, heat, and oxygen (the fire-triangle) in each of the functional sub-areas. The FRI values are determined from the following algorithms:

Fuel Load Weighting = Wood Usage + Other Combustible Materials

Heat Source Weighting = Heat (Sparks and Open Flame)

Oxygen

FRI = Fuel Load Weighting x Heat Source Weighting x Oxygen

The weighting values which have been assigned to "HEAT SOURCE WEIGHTING" represent the authors' estimates only. These values take into account such things as:

- The methane monitors on the wall which are interlocked with the face equipment to automatically stop operations at methane concentrations greater than 1.25 percent.
- A methane check done in the "top corner" prior to blasting in the return gateroad or development areas, and only "permissible explosives" are used.
- The requirement for "approved" electrical equipment.
- The requirement for a water scrubber on all internal combustion equipment to prevent exhaust sparks.
- The limited potential for spontaneous combustion of coals in the Sydney Coalfield.

The weighting for "OXYGEN" is considered to be a value of one (1) when there is sufficient oxygen to support combustion. The only functional sub-areas where the oxygen concentration is not normally high enough to support combustion are the gob and sealed abandoned panels where oxygen weights of 0.3 and 0.1 respectively are assigned.

The "FUEL LOAD WEIGHTING" is determined through "weighting values" assigned to each of the fuel sources on a basis of volume of material present and its flammability. The flammability values were assigned using the calorific value required to initiate fire (Both et al:, 1982):

Fuel	Calorific Value (kJ/kg)	FRI Maximum Flammability Rating
Carbon	33,910	6
Hydrogen	14,340	10
Methane*	55,500	1
Coal	31,000	7
Timber	17,500	10
Fuel Oil	40,000	5
Self Extinguishing Belt	33,000	6
Fire Retardant Belt	25,000	8
Tyres	42,000	4
Electrical Cable	29,000	7

* Methane + Aerosol Coal Dust has a much lower calorific value. A rating of 7 is used in the FRI Model.

These FRI "FUEL LOAD WEIGHTING" assigned to each fuel source is determined by modifying the maximum flammability rating by a volume factor. No discrete values for usage volume have been established; however, suitable ranges and weighting modificaiton factors were assigned:

Usage Volume	Factor
low	0.1
medium	0.5
large	1.0

The combustible materials which have been assigned to each of these usage volume categories are as follows:

Usage Volume	Wood	Other Combustible Materials
low (0.1)	-remedial support member	-diesel fuel -garbage
medium (0.5)	-construction material -cavity filling -rail ties	-electrical cable -lubricants
large (1.0)	-wood packs -lagging	-coveyor belts -methane + aerosol coal -settled coal dust -coal (production)

The FRI model which has been developed for a CBDC coal mine is shown on Table 7.1. The model generates an index rating for each functional sub-area of the mine for two conditions of wood usage; "WITH WOOD" as it is currenty practiced and "WITHOUT WOOD." The top five (5) rankings for areas of major concern under these two scenarios are:

Location	FRI With Wood	FRI Without Wood	FRI Reduction
1. Intake Gateroad	1541	713	828
2. Face	1302	1147	155
3. Fan Location	1134	588	546
4. Exhaust Gateroad	767	299	468
5. Slope and Gateroad Development	702	377	325

As will be noted the advantages of wood replacement in it's limited capacity on the face has minimal effect on the FRI, as would be anticipated.

The information presented in the FRI model, Table 7.1, does not comprehend the reduction in fire hazared (FRI) provided by the replacement of each individual wood usage by functional sub-area. This assessment is required to prioritize a wood replacement program at CBDC coal mines. This work is presented in Table 7.2.

TABLE 7.1: Fire Rating Index (FRI) Model

		FUEL LOAD WEIGHTING													
AREAS	FUNCTIONAL SUB-AREAS	WOOD USAGE						OTHER COMBUSTIBLE MATERIALS							
		WOOD PACKS	LAGGING	CONSTRUCTION MATERIAL	CAVITY FILLING	REMEDIAL SUPPORT	RAIL TIES	METHAANE + AEROSOL COAL DUST	SETTLED COAL DUST	CONVEYOR BELTS	ELECTRICAL CABLES	DIESEL FUEL	LUBRICANTS	GARBAGE	COAL PRODUCTION
WORKING PANEL	FACE	-	-	-	5	-	-	15	7	-	4	-	3	1	7
	INTAKE GATEROAD	10	10	5	5	1	5	-	-	6	4	10	3	1	7
	EXHAUST GATEROAD	10	10	5	5	1	5	12	7	-	-	-	3	1	
	GOB	-	-	-	5	-	-	7	7	-	-	-	-	-	-
MAIN SLOPES + PERMANENT INSTALLATIONS	BELT LINE SLOPES	-	10	5	5	1	5	7	7	6	4	-	3	-	7
	MAN RIDING SLOPES (WITH BELTS)	-	10	5	5	1	5	-	7	6	4	-	3	1	7
	MAN RIDING SLOPES (WITHOUT BELTS)	-	10	5	5	1	5	-	-	-	4	-	3	1	-
	FAN LOCATIONS	-	10	5	5	1	5	-	7	6	4	-	3	1	7
	COAL BUNKER	-	-	-	-	-	-	7	7	-	4	-	3	-	7
DEVELOPMENT AREAS	SLOPES	-	10	5	5	-	5	7	7	-	4	-	3	1	7
	GATEROADS	-	10	5	5	-	5	7	7	-	4	-	3	1	7
	FACE LINE	-	10	5	5	1	-	7	7	-	-	-	-	1	7
ABANDONED AREAS	SEALED PANEL	10	10	5	5	1	-	7	7	-	-	-	-	-	-
	UNSEALED/COMPLETED PANEL	10	10	5	5	1	-	7	7	-	-	-	-	-	-
	CUNDY EXHAUST AIRWAY	10	10	5	5	1	-	7	7	-	-	-	-	-	-

		(A) Σ FUEL LOAD WEIGHTINGS		HEAT SOURCE WEIGHTING (SPARKS AND OPEN FLAMES)								(B) Σ HEAT SOURCE WEIGHTINGS	(C) OXYGEN	(AxBxC) FIRE RATING INDEX (FRI)	
GARBAGE	COAL PRODUCTION	WITH WOOD	WITHOUT WOOD	SHEARING OR CUTTING	BLASTING	ELECTRICAL FLASH	MECHANICAL SPARK	INTERNAL COMBUSTION	CONTRABAND	OXIDATION	SPONTANEOUS COMBUSTION			WITH WOOD	WITHOUT WOOD
1	7	42	37	20	-	5	4	-	1		1	31	1	1302	1147
1	7	67	31	10	-	5	4	2	1		1	23	1	1541	713
1		59	23	-	6	1	4	-	1		1	13	1	767	299
-	-	19	14	-	-	-	-	-	-		1	1	0.3	6	4
-	7	60	34	-	-	5	4	-	-		-	9	1	540	306
1	7	54	28	-	-	5	4	-	1		-	10	1	540	280
1	-	34	8	-	-	5	4	-	1		-	10	1	340	80
1	7	54	28	-	-	10	10	-	1		-	21	1	1134	588
-	7	28	28	-	-	5	4	-	-		1	10	1	280	280
1	7	54	29	10	3	-	-	-	-		-	13	1	702	377
1	7	54	29	10	3	-	-	-	-		-	13	1	702	377
1	7	43	22	-	3	-	-	-	-		-	3	1	129	66
-	-	45	14	-	-	-	-	-	-		1	1	0.1	5	0
-	-	45	14	-	-	-	-	-	-		1	1	1	45	14
-	-	45	14	-	-	-	-	-	-		1	1	1	45	14

TABLE 7.2: Reduction in Fire Rating Index Values for Individual Wood Usage Replacements

AREA	WOOD USAGE REPLACEMENT FUNCTIONAL SUB-AREA	FUEL LOAD WEIGHTING							HEAT SOURCE WEIGHTING	OXYGEN	F	
		WOOD PACKS	LAGGING	CONSTRUCTION	MATERIAL	CAVITY FILLING	REMEDIAL SUPPORT	RAIL TIES			WOOD PACKS	LAGGING
WORKING PANEL	FACE	42	42	42		37	42	42	31	1	1302	13
	INTAKE GATEROAD	57	57	62		62	66	62	23	1	1311	13
	EXHAUST GATEROAD	49	49	54		54	58	54	13	1	637	6
	GOB	19	19	19		14	19	19	1	0.3	6	
MAIN SLOPES + PERMANENT INSTALLATIONS	BELT LINE SLOPES	60	50	55		55	59	55	9	1	540	4
	MAN RIDING SLOPES (WITH BELT)	54	44	49		49	53	49	10	1	540	4
	MAN RIDING SLOPES (WITHOUT BELT)	34	24	29		29	33	29	10	1	340	2
	FAN LOCATIONS	54	44	49		49	53	49	21	1	1134	9
	COAL BUNKER	28	28	28		28	28	28	10	1	280	2
DEVELOPMENT AREAS	SLOPES	54	44	49		49	54	49	13	1	702	5
	GATEROADS	54	44	49		49	54	49	13	1	702	5
	FACE LINE	43	33	38		38	42	43	3	1	129	
ABANDONED AREAS	SEALED PANEL	35	35	40		40	44	45	1	0.1	4	
	UNSEALED/COMPLETED PANEL	35	35	40		40	44	45	1	1	35	
	CUNDY EXHAUST AIRWAY	35	35	40		40	44	45	1	1	35	

OXYGEN	FRI VALUES FOR INDIVIDUAL WOOD USAGE REPLACEMENTS						ORIGINAL	REDUCTION IN FRI FOR INDIVIDUAL WOOD USAGE REPLACEMENTS						Σ
	WOOD PACKS	LAGGING	CONSTRUCTION MATERIAL	CAVITY FILLING	REMEDIAL SUPPORT	RAIL TIES		WOOD PACKS	LAGGING	CONSTRUCTION MATERIAL	CAVITY FILLING	REMEDIAL SUPPORT	RAIL TIES	
1	1302	1302	1302	1147	1302	1302	1302	–	–	–	155^{3}	–	–	155
1	1311	1311	1426	1426	1518	1426	1541	230^{1}	230^{1}	115^{5}	115^{5}	23	115^{5}	828
1	637	637	702	702	754	702	767	130^{4}	130^{4}	65^{9}	65^{9}	13	65^{9}	468
0.3	6	6	6	4	6	6	6	–	–	–	2	–	–	2
1	540	450	495	495	531	495	540	–	90^{8}	45	45	9	45	234
1	540	440	490	490	530	490	540	–	100^{7}	50	50	10	50	260
1	340	240	290	290	330	290	340	–	100^{7}	50	50	10	50	260
1	1134	924	1029	1029	1113	1029	1134	–	210^{2}	105^{6}	105^{6}	21	105^{6}	546
1	280	280	280	280	280	280	280	–	–	–	–	–	–	–
1	702	572	637	637	702	637	702	–	130^{4}	65^{9}	65^{9}	–	65^{9}	325
1	702	572	637	637	702	637	702	–	130^{4}	65^{9}	65^{9}	–	65^{9}	325
1	129	99	114	114	126	129	129	–	30	15	15	3	–	63
0.1	4	4	4	4	4	5	5	1	1	1	1	1	–	5
1	35	35	40	40	44	45	45	10	10	5	5	1	–	31
1	35	35	40	40	44	45	45	10	10	5	5	1	–	31
							Σ	381	1171	586	743	92	560	3533

7.2 Discussion of Flame Spread

The rate of flame spread in a mine airway, given that there is an ignition, is a very complex phenomenon which involves such factors as:

- flame spread properties of each combustible material;
- flame spread properties of mixtures (CH_4 + aerosol coal dust);
- intensity and duration of ignition;
- available volume of the combustible materials;
- ventilation airflow velocity;
- interaction of multiple combustion processes (eg. wood + settled coal dust).

This detailed assessment can only be accomplished through extensive experimental work and large scale or in-mine fire testing. The variables which control flame spread rates are too extensive to be undertaken in the context of the FRI model. Though it is commented that rate of flame spread is of paramount concern to ascertain the risk due to fire in a coal mine, it will not be undertaken to include this parameter at this time.

7.3 Recommended Wood Replacement Priorities

Based on the information which has been presented in the FRI model, Table 7.2, a wood replacement program at CBDC is proposed to effect a reduced fire hazard in the mine. The priorities have been established on wood usage by functional sub-area and are listed in Table 7.3, for the top nine (9) priorities only, in descending order of importance. It is noted that the larger the reduction in FRI value, created by a wood replacement, the more significant the fire hazard reduction.

At this point it is commented that these priorities are based on reduced "fire ignition potential" only, as predicted by the FIRE RATING INDEX model. No attempt is made in this report to comprehend the "flame spread potential" for each of these ignition situations. It is proposed that this

TABLE 7.3: Recommended Wood Replacement Program By Functional Sub-Area and Wood Usage for CBDC Based on a Reduced Potential For Fire Ignition

Priority	Functional Sub-Area	Wood Usage	FRI value Reduction
1	Intake Gateroad	Lagging	230
	Intake Gateroad	Wood Packs	230
2	Fan Location	Lagging	210
3	Face	Cavity Filling	155
4	Exhaust Gateroad	Lagging	130
	Exhaust Gateroad	Wood Packs	130
	Slope Development	Lagging	130
	Gateroad Development	Lagging	130
5	Intake Gateroad	Construction Material	115
	Intake Gateroad	Cavity Filling	115
	Intake Gateroad	Rail Ties	115
6	Fan Locations	Construction Material	105
	Fan Locations	Cavity Filling	105
	Fan Locations	Rail Ties	105
7	Man-riding Slopes	Lagging	100
8	Belt-line Slopes	Lagging	90
9	Exhaust Gateroads	Construction Material	65
	Exhaust Gateroads	Cavity Filling	65
	Exhaust Gateroads	Rail Ties	65
	Slope Development	Construction Material	65
	Slope Development	Cavity Filling	65
	Slope Development	Rail Ties	65
	Gateroad Development	Construction Material	65
	Gateroad Development	Cavity Filling	65
	Gateroad Development	Rail Ties	65

extension to the FRI model would further enhance the ability to plan wood replacement priorities.

The priorities for wood replacement at CBDC coal mines are presented in Table 7.4 in descending order of importance, based on the location and frequency of appearance of a particular wood usage in Table 7.3.

TABLE 7.4 Recommended Wood Replacement Program by Wood Usage for CBDC Based on a Reduced Potential for Fire Ignition

Replacement Priority	Wood Usage	Priority by Functional Sub-area
1	Lagging	1, 2, 4, 4, 4, 7, 8
2	Wood Packs	1, 4
3	Cavity Filling	3, 5, 6, 9, 9, 9
4	Construction Material	5, 6, 9, 9, 9
5	Rail Ties	5, 6, 9, 9, 9
6	Remedial Support Member	--

8.0 RECOMMENDED WOOD REPLACEMENT PROGRAM FOR CBDC COAL MINES

The wood replacement priorities which have been established for CBDC in the preceeding section of this report are presented in Table 8.1 along with the available replacement technologies for wood as established in Phase II - Part I. This listing segregates the potential replacement technologies based on the criteria listed below and proposes systems deemed most appropriate for CBDC. The criteria used for this evaluation are as follows:

- not commerically available, research only;
- not viable/suitable in normal operations;
- not suitable - improved technology available;
- suitable but requires imported material (comment: licensing aggrements could be pursued to produce these materials locally - to avoid high transportation costs associated with imported bulk materials)
- recommended wood replacement technology.

The recommended wood replacement technologies, as presented in Table 8.1, are reviewed in Table 8.2 on a basis of the major materials required for the uses. From this review, it is concluded that a wood replacement program for gateside packs, cavity filling, and construction material can be initiated using either anhydrite or Portland cement based techniques. A preliminary raw material cost analysis for OPC, fly ash, anhydrite, and major chemicals is conducted in Section 8.1.

A program for the replacement of wood lagging is based on welded wire mesh lagging products. Several lagging systems incorporating grout-filled envelopes and complete backfilling systems are reviewed. Sprayed concrete linings (shotcrete and gunite) are evaluated; however, restricted usage to main roadway is discussed.

8.1 Raw Materials Costs for Replacement Technologies

The raw materials required in large quantities for the technologies identified for gateside packs, cavity filling, and construction material are anhydrite, cement, fly ash, and chemicals. Each of these materials is investigated as follows:

TABLE 8.1 REVIEW OF WOOD REPLACEMENT ALTERNATIVES FOR CBDC COAL MINES WITH RECOMMENDATIONS

PHASE I REFER-ENCE NO.	WOOD REPLACEMENT TECHNOLOGY	NOT COMMERCIALLY AVAILABLE RESEARCH ONLY	NOT VIABLE/ SUITABLE IN NORMAL OPERATIONS	NOT SUITABLE IMPROVED TECHNOLOGY AVAILABLE	SUITABLE BUT REQUIRES IMPORTED MATERIAL	RECOMMENDED WOOD REPLACEMENT TECHNIQUE	COMMENTS
3.0	FIRE RETARDANT TREATMENTS						
3.1	Chemical Impregnation			X			
3.1	Precharring			X			
3.2	Chemical Coating			X			
3.2	Mine Sealant Coatings					X	• Standing Timber Only
3.2	Polymer Based Coatings		X				
3.2	Intumescent Paint Coatings		X				
4.0	CONSTRUCTION MATERIALS						
	Normal Weight Concrete Block					X	
	Autoclave Aerated Concrete Block			X			
	Fibre-reinforced Shotcrete Panels					X	
	Anhydrite Stoppings					X	
	Steel Panels & Framing					X	
5.0	LAGGING MATERIALS						
5.1	Corrugated Steel Sheets			X			
5.1	Steel Liner Plates		X				
5.1	Wire Mesh Lagging					X	
5.1	Strutlag				X		
5.1	Rockbolts & Wire Mesh					X	
5.2	Complete Roadway Backfilling					X	• Cement, Anhydrite, Foamed Grout
5.2	Partial Roadway Backfilling					X	• Cement Filled Grout Envelope
5.2	Sprayed Concrete					X	
5.2	Precast Lagging Boards	X					
6.0	GATESIDE PACKWALL CONSTRUCTION						
6.4	Precast Concrete Block						
	Autoclave Aerated Concrete Block			X			
	Steel-fibre Reinforced Concrete Block				X		• Suitable on Limited Scale for Remedial Support
	Reinforced Light-Weight Aggregate Concrete Block			X			• Possible Construction Material if Produced Locally
6.5	Pneumatically Placed Packs						
	Complete Face Backfilling			X			
	Strip Packwall Construction					X	• Pneumatically Stowed Anhydrite
6.6	Mechanically Placed Packs						
	Slusher, Blade & Ram			X			
6.7	Hydromechanically Placed Packs						
	Synthetic Anydrite Packs			X			
	Pack Consolidation			X			
	Thyssen System			X			
	Warbret System			X			
	Aquapak System			X			
	Astrapak (Tekpak) System				X		
	Flashpack System					X	
7.0	CAVITY STABILIZATION TECHNIQUES						
7.1	Anhydrite					X	
	Strain Absorbent Modules					X	• May Be Filled With Cementitious Material
	Inflatables		X				• Emergency Only
	Chemical Foams		X				
	Cementaceous Products						
	Foamed Cement					X	
	Aqualight				X		
	Cavityfill 5				X		
	Fly ash Cement	X					• Not Proven In Production Setting
7.2	Strata Reinforcement						
	Grout Injection					X	• Only For Large Cavities
	Strata Dowelling					X	• Only For Large Cavities (Not Controlled By Other Methods)
8.0	NEW FACE DEVELOPMENT/ STRIPPING COMPLETED FACE						
	Strata Reinforcement					X	• Very Limited Wood Replacement
	Wire Mesh & Steel Cable					X	• Very Limited Wood Replacement

TABLE 8.2 RECOMMENDED WOOD REPLACEMENT TECHNIQUES AND MAJOR MATERIALS REQUIRED

MAJOR MATERIAL / USE	CEMENTITIOUS	ANHYDRITE	STEEL	COMMENTS
Lagging	• Roadway Backfilling	• Roadway Backfilling	• Wire Mesh Panels	• Supplemental Support For Tunnel Used In Conjunction With Wire Mesh Lagging
Packs	• Flashpack	• Pneumatically Placed • Hydromechanically Placed		
Cavity Fill	• Foamed Cement	• Pneumatically Placed Anhydrite (Documented Use On the Face Only)	• Strain Absorbent Modules	• Requires Rudimentary Floor in Cavity
Construction Material	• Normal Weight Concrete Block • Fibre Reinforced Shotcrete Panels	• Anhydrite Stoppings	• Steel Panels and Framing	
Rail Ties			• Steel Ties	• Currently On Trial at CBDC
Remedial Support Member	• Steel Fibre Reinforced Concrete Block (Burrell)			• Imported Material
Fire Proof Standing Timber	• Mine Sealant Coatings			

Anhydrite Material Costs

a. Material Cost f.o.b. Quarry Site approximately $15/tonne (Note: This price is not negotiated and could likely be reduced if contracts are placed.)

b. Transportation Costs by highway truck:
Price/tonne/km:
$0.08/tonne/km for first 100 km, plus
$0.06/tonne/km for each additional km

Little Narrows Gypsum to CBDC (120 km):
$0.08/tonne/km x 100 km, plus
$0.06/tonne/km x 20 km = $ 9.20

Fundy Gypsum to CBDC (460 km):
$0.08/tonne/km x 100 km, plus
$0.06/tonne/km x 360 km = $29.60

c. Total Anhydrite Costs at CBDC:
Anhydrite from Little Narrows ($15 + $9.20)
= $24.20/tonne
Anhydrite from Fundy Gypsum ($15 + $29.60)
= $44.60/tonne

Unlimited supply volumes are available from either mine site.

Note: It is commented that the transportation costs of anhydrite from Little Narrows Gypsum Co. Ltd. could be significantly lower than indicated. CBDC currently ships coal by highway truck to several power stations in Nova Scotia and the "empty" coal haulage units pass Little Narrows Gypsum Co. Ltd. on the return trip to Sydney. Contractural agreements with the private transport company providng this service could further reduce the anhydrite cost/tonne at CBDC.

Portland Cement Costs

The cost of Portland cement f.o.b. Mine Site has been estimated by two local suppliers as:

Canada Cement LeFarge Co. Ltd.
$133.21/tonne + 10% provincial tax
St. Lawrence Cement Co. Ltd.
$160/tonne + 10% provincial tax

Note: Canada Cement LeFarge produces OPC at Brookfield, N.S. St. Lawrence Cement imports the OPC from Quebec; however, it uses some raw materials from N.S. in its production.

Either cement supplier can provide the quantities of product which may be required by CBDC under any scenario of wood replacment.

Fly Ash Costs

The Nova Scotia Power Corporation (NSPC) currently has a contract with L.E. Shaw Co. Ltd. to market fly ash for "normal" cement applications at a price of $32.25/tonne + 10% provincial tax, f.o.b. silo at Lingan, Nova Scotia. L.E. Shaw Co. Ltd. also uses this product in some of its cement based products. It is possible the intended use for fly ash in packs and cavity filling is not "normal" cement use and a direct sale of fly ash to CBDC by NSPC could be struck at a price significantly lower than the current market price from L.E. Shaw Co. Ltd.

Chemical Costs

The major chemicals used as accelerators in the recommended systems include either of the following:

- Ferrous Sulphate - Anhydrite and Fly Ash Cement Systems
- Aluminum Sulphate - Fly Ash Cement Systems
- Potassium Sulphate - Anhydrite Systems

The lowest cost product of these three is the ferrous sulphate for which the following costing f.o.b. CBDC is given:

Truck load f.o.b. Arvida, P.Q. (25 tonne lot)	$ 138/tonne
Shipping Cost	$1500/load
Product Cost at CBDC	
$138/tonne + ($1500/load/25 tonne/load)	$ 195/tonne

8.2 Cost of Replacement Technologies

The following cost information is developed to provide a preliminary estimate of material costs for the alternate systems identified for use at CBDC. These material cost estimates are based on either:

- quoted cost information from manufacturers;
- extended raw materials costs;
- published costs.

Cementitious Materials - Gateside Packs and Cavity Filling

The fly ash cement materials which have been identified in the review as the most appropriate OPC-based material is anticipated to have a material cost of $95/m^3 (Cain, 1986). The current Astrapak material in use at CBDC is estimated to have a cost of $150/m^3, which is greatly affected by shipping costs from the U.K.

A brief costing estimate has been prepared on the fly ash cement by the author using a known fly ash cement mix used for gateside pack construction in the UK.

Fly Ash (Bulk)	930 kg	$33
OPC	255 kg	42
Ferrous Sulphate	100 kg	14
Bentonite	9 kg	6
		$95/m^3

This estimate confirms the material price estimate previously discussed.

Cost per meter of roadway for fly ash cement gateside fly packs:

Fly Ash Pack Size:
2 m high x 2 m wide = 4 m^3/m

Cost of fly ash cement packwall:
$95/m^3 x 4 m^3/m = $380/m of roadway

No cost estimate is included for the gateside shutt required with the fly ash cement packwall placement.

Anhydrite - Gateside Packs

Anhydrite packs require 2.15 tonnes/m^3 of anhydrite material per m^3 of pack plus an accelerator.

Anhydrite Pack Size = 2 m x 2 m = 4 m^3/m
Anhydrite in Pack =
($24.20/tonne x 2.15 tonne/m^3 x 4 m^3/m) = $208/m
Accelerator (same as fly ash system) = $ 14/m

Anhydrite Pack Material Cost $222/m of roadway

A gateside wire mesh mat will be required to retain the anhydrite pack during placement. This mat comprises 8 mm to 10 mm bars with 6 mm x 6 mm x 0.6 mm netting.

Cost of mat:
° Drahtwerke Rosler Soest GmbH & Co., KG = $7.80/m^2
Required mat per meter of tunnel (approx.) 2 m^2
Mat Cost = $7.80/m^2 x 2 m^2/m
= $15.60/m of tunnel

Total Anhydrite Pack Material Cost plus wire mat shutter = $237.60/m of roadway

Roadway Lagging Blocking and Backfilling

Several techniques have been identified as wood replacement techniques for wood lagging and backfilling behind the steel arch supports. These lagging techniques are:

- weld mesh lagging;
- sprayed concrete (which is often used in conjunction with weld mesh reinforcement).

Weld mesh lagging can be supplied in several forms (rolls, back lagging panels, extensible panels) which impacts on the material cost of the product. Only extensible mats are estimated here to provide a cost indication for this technology:

- BRC Engineering Limited, UK

- roll or panel lagging with helical binders (75 mm x 75 mm x 3.45 mm wire)	$\$3.50/\text{m}^2$
- gateroad perimeter	$10.7\ \text{m}^2$
- Cost of weld mesh lagging	$40/m of roadway

- Drahtwerke Rosler Soest GmhB & Co., KG

- Extensible Mat (100 mm x 100 mm x 6 to 8 mm wire)	$\$3.90/\text{m}^2$
- Perimeter of roadway	10.7 m
- Cost of weld mesh lagging 10.7 x $\$3.90/\text{m}^2$	$41.73/m of roadway

Weld mesh lagging has also been identified as a lagging product used in conjunction with a rock bolted roadway (integral bolting system where steel arches are not used as a main support member). At the current time CBDC does not use rock bolts as an integral support system in roadways. Consequently, further consideration of this alternative will not be addressed in this report as it cannot currently be utilized at CBDC due to lack of integral rockbolted roadways.

Adequate blocking and backfilling behind the steel arches in a weld mesh lagged roadway can be accomplished by:

- wood blocking;
- grout envelopes (partial roadway backfilling);
- complete roadway backfilling.

It is imperative that adequate blocking and backfilling of the arches be performed at the time of installation to achieve the maximum support capacity of the arch. Point blocking by wood at specific locations around the arch does not provide the maximum support capacity of the arch due to point loading. Wood blocking also creates a fire hazard.

The grout envelope method of blocking provides a much improved continuous blocking for the arch member and permits the full strength of the arch to be utilized.

Material cost of grout envelopes (material + stitching + grout) (MRDE, 1980(a)) are as follows:

- Single Envelope behind the arch - $120/m of tunnel;
- Full Width Envelope - $200/m of tunnel;
- Tadpole Envelope - $240/m of tunnel.

Complete roadway backfilling accomplishes more than the provision of a lagging surface for the roadway. This process creates a thick monolithic shell around the arch profile of the roadway which forms an integral part of the support system for the roadway. The lagging material for this purpose comprizes 10 mm diameter rods and fly screen netting to retain the backfill material plus a covering material for hydraulically placed backfill.

Material costs for roadway backfilling methods (cementitious material, anhydrite, foamed grout) are as follows:

- Backfill with cementitious material (usually pack material) requires 3 m^3 mortar/m of roadway (Eulgem, 1985):
  - Cost of cemented backfill material (fly ash cement):
    3 m^3/m x $95/$m^3$ — $285/m
  - Unit cost of special weld mesh lagging (10mm bars with 6 mm x 6 mm wire mesh with netting) — $9/$m^2$
    Cost of mesh 10.7 m^2/m x $9/$m^2$ — $96.30/m
  - Total cost of cement backfill system — $381.30/m

- Backfill with anhydrite material requires 3 m^3 of anhydrite/m of roadway (Leyhe, 1985):
  - Cost of anhydrite:
    3 m^3/m x $68/$m^3$ — $204/m
  - Cost of weld mesh lagging (above) — $96.30/m
  - Total cost of anhydrite backfilling — $300.30/m of roadway

Foamed (light) grouts have been discussed in Phase II - Part I as a new roadway backfilling technology which reduces the mass of cementitious material required to fill a void.

The grouts tested had a normal density of 1.5 tonnes/m^3 but when foamed had a filling factor of 0.91 tonnes/m^3 (average) and 0.7 tonnes/m^3 (maximum). This foamed grout technology would reduce the previously discussed cementitious roadway backfill material costs if used:

° Backfill with foamed (light) grout at 0.9 tonne/m^3:

- Cost of foamed grout material $285/m x (0.9 t/m^3 / 1.5 t/m)	$171/m
- Cost of weld mesh lagging (above)	$96.30/m
- Total cost of foamed roadway backfill	$267.30/m of roadway

Note: The additional capital and operating costs to accomplish this process should be evaluated against the cost savings in material.

A final technique for replacing wood lagging would be to pneumatically place a concrete shell around the roadway (shotcrete or gunite). This shell usually comprises a 75 mm thick shell and represents approximately 1.5 m^3 of shotcrete per meter of roadway (this value includes an allowance for back splash) (MRDE, 1980), and 1.2 m^3 of gunite per m of roadway (back splash not as great with gunite.).

Sprayed Concrete Material Cost:

° Shotcrete (aggregate size less than 25 mm):

- Cost estimate (MRDE, 1980(b))	$165/m of roadway

° Gunite (aggregate size less than 5 mm), (Prebagged, dry mix):
  - Cost estimate of various gunite materials (Krantz, 1984):

dry mix	steel fibre reinforced	$317/m of roadway
	fibreglass reinforced	$406/m of roadway
	polypropylene reinforced	$282/m of roadway
wet mix	steel fibre reinforced	$540/m of roadway

It is commented that the coarse refuse of Victoria Junction has been identified to be of a size consist suitable for use as an aggregate in shotcrete. This usage of the refuse can only be conducted if the refuse does not contain any minerals which would be deleterious to the cement. Chemical analysis and physical testing of the refuse would be required before this potential use of refuse was employed. The prices quoted for sprayed concrete represent commercially available bagged products. Considerably lower material costs could be realized if bulk batching of the required mix was done at the mine site using refuse as aggregate.

Sprayed concrete linings are usually placed in roadways which experience a limited amount of deformation to minimize roadway lining repair costs. Consequently, usage should be restricted to main roadways. Its use for gateroads at CBDC would not appear to be practical.

Cavity Filling

The materials used in cavity filling have been previously discussed and include the following materials along with their previously estimated material costs:

- foamed cements	$\$57/m^3$
- fly ash cement	$\$95/m^3$
- pneumatically placed anhydrite	$\$68/m^3$

Each of these systems requires a rudimentary floor construction to support the cavity filling material. The foamed cement requires a pack bag or inflatable (lower cost dunnage bag could be used) to retain the fluid grout mixture.

Strain absorbent modules provide an excellent cavity filling technique; however, it does require mine personnel to work in the unprotected cavity area. Material costs for SAM's have been published (Prod & Prod Bulletin, NCB) at approximately $50 per m^3 depending on the mesh type used in the construction of the SAM.

Inflatables represent a high cost cavity filling technique. A 3.7 m diameter sphere shaped inflatable costs $5,000 in neoprene and $2,200 in mylar (Dalzell and Curth, 1984). These units could provide a rapid response method of cavity filling in the event of an emergency; however, much less expensive methods have been previously discussed.

Aqualight is an excellent cavity filling product available in the UK as a proprietory mix. Depending on the volume required per annum it should be evaluated whether importing sufficient supplies or liscenced manufacture of the product in Canada would best satisfy CBDC requirements if this method of cavity filling is selected.

Other Wood Usages

The materials cost information which has been presented represents the replacement for a large majority of wood usages in underground coal mines. Other wood uses such as rail ties and remedial support members are not detailed, as only single products are outlined as replacements and these applications represent a limited volume usage for wood.

8.3 Health and Safety Issues

The introduction of either the use of cementitious materials or the pneumatic placement of anhydrite represent new health and safety issues for the CBDC coal mines. These factors must be addressed in the final choice to be made between these two systems. These issues are outlined in the appendix presented in Section 9, Phase II - Part II for:

- Rules for Handling and Using Cement-Based Materials for Pump Packing
- Precautions To Be Taken When Spraying Concrete Underground With or Without The Use of Cement Setting Accelerators
- Problems Associated with Pneumatic Stowing

8.4 Conclusions

Wood replacement in underground coal mines represents one positive technique to reduce th risk of fire ignition and propogation throughout the mine structure. A variety of technologies have been developed, or are currently being developed, to accomplish this.

A review of wood usage of CBDC and a subsequent analysis of the risk of fire ignition in wood has demonstrated a priority for wood replacement as follows:

- wood lagging;
- wood gateside packs;
- wood cavity filling structures;
- wood construction materials;
- wood rail ties;
- wood remedial support members.

It is not the intent of this report to select a single alternative but to present the alternative systems which will derive maximum material usage benefits to Cape Breton Island and region.

Wood lagging can most effectively be replaced by weld mesh lagging products. A variety of these products has been developed to incorporate roadway backfilling systems using either a hydromechanically placed cementitious material or a pneumatically placed anhydrite. Partial or complete backfilling systems can be employed.

As complete backfilling systems represent high unit costs, they are normally restricted to use in high stress areas such as roadway intersections or permanent roadways in high stress zones. Sprayed concrete can also be used in conjunction with weld mesh panels to provide a roadway lining technique for areas that do not experience significant deformation.

At the current time, no manufacturing facilities exist in North America to produce the large variety of weld mesh products reviewed in this report. This product line is produced on highly automated, capital intensive equipment. If such a facility could be attracted to establish in Cape Breton Island it would represent an expansion to the industrial base of the area and produce a product that would supply the North American market.

The analysis which has been conducted indicates that two systems are technically suitable to replace wood usage in gateside packs, cavity filling and construction applications, in the underground coal mines. These systems are:

- fly ash cements (hydromechanical system);
- anhydrite (hydromechanical and/or pneumatic system).

Extensive resources have been identified in Cape Breton Island and Nova Scotia to supply raw materials for either of these replacement technologies. Both systems represent a new technology for CBDC. Health and safety issues related to both systems have been outlined for subsequent review.

A decision will necessarily have to be made between these two systems based on economic, ergonomic, and operational considerations. This decision will necessarily involve individuals from research, consulting, operating, and supplier organizations and cannot be attempted within the scope of this review.

It would appear, however, that the wide range of applications for cementitious products in underground coal mines is currently somewhat broader than exists for anhydrite and would tend to favour the cement based system. It is conceivable that from a central supply of OPC into the mine (likely to be delivered by a pneumatic system) many diversified cement products could be blended underground and supplied via in-mine distribution systems to the point of use. Products such as:

- flashpack system for gateside packs;
- foamed grout for roadway backfilling and cavity filling;
- sprayed concrete for roadway lining, construction of stoppings, doorways, isolation rooms, etc.;
- cementitious grouts for strata reinforcement;

will be avialable to replace the traditional uses of wood in CBDC coal mines.

Conversely, it must be considered that materials cost for anhydrite are lower than for the cement based system. Also, recent work on anhydrite employing fly ash as an additive has expanded the traditional applications of anhydrite in coal mines. Continued work on product development for anhydrite may soon produce a range of applications as broad as cement-based products.

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10.0 APPENDIX

10.1 Rules For Handling and Using Cement-Based Materials for Pump Packing (McCarthey and Robinson, 1981)

These rules have been formulated for your own safety and protection and to assist Management in the discharge of their responsibilities.

A. OPERATIONAL PROCEDURES

1. Loading on the Surface

(a) Cement-based materials will be loaded into suitable vehicles.
(b) No damaged bags should be loaded.
(c) No bags to be loaded above the rim of the vehicle.
(d) No material which can burst bags shall be loaded or transported on the same vehicle as cement bags.
(e) Protective clothing as provided shall be worn.

2. Transport of Packbind

(a) Off-loading en route shall be avoided unless authorized by an official.
(b) Bags will be stacked at pumping station clear of track and haulage rope.
(c) Empty bags shall be disposed of in a manner approved by the Manager. They shall not be transported on conveyors.
(d) Bags inadvertently broken during transit shall be rebagged immediately.

3. Protective Clothing and Equipment To Be Used

(a) Protective clothing will be provided and specified by the Manager.

4. Operational Precautions

(a) Direct contact with cement-based materials (wet or dry) should be avoided.
(b) The cement pumpline must NOT be disconnected while the pump is running.

(c) Any defect in equipment shall be immediately notified to the Official in Charge.
(d) Packs shall not be placed unless communications between pack and grout pump are in working order.
(e) Dust suppression equipment, where provided, must be used during packing operations.
(f) Special care shall be taken during flushing down operations to prevent splashing and spillage in the working area.

5. Medical Aspects

(a) A high standard of personal hygiene must be exercised when using cement-based materials.
(b) Barrier cream as provided should be used.
(c) Wet or dry cement-based materials entering the eyes should be irrigated immediately using eyewash provided.
(d) In the event of cement-based materials coming into contact with the skin the affected part must be washed thoroughly as soon as possible.
(e) In the event of any doubt regarding treatment underground, you should report to the Medical Centre on arrival at the surface.

6. General

(a) Men allergic to cement-based materials shall not work on cement-based materials.
(b) Packbind shall not be used for any purpose other than pump packing.

B. SCHEDULE OF PROTECTIVE CLOTHING

1. The cement pump operators and the cement pump feeders and pack attendants are to be provided with clean overalls at least once per week and more frequently if necessary. The men should obtain these overalls from the Baths Office and return them in exchange for a clean set.

2. A locked toolbox is to be kept in each gate of each District containing the following items of use as required:

   (a) 1 set of Monsson Gear
   (b) 2 sets of Rubber Aprons
   (c) 2 pairs of Goggles
   (d) 2 pairs of Waterproof Trousers
   (e) 2 sets of Clean Overalls.

   The Cement Pump Operator is to be responsible for checking the contents of the box each shift and to his Official. Should the overalls be used on any shift, the person using them must return them to the surface and arrange for a replacement to be brought in by the oncoming shift.

3. Workmen must be responsible for obtaining and renewing their own gloves and goggles from the Medical Centre.

4. Men unloading cement bags must wear gloves at all times.

10.2 Precautions To Be Taken When Spraying Concrete Underground With or Without The Use of Cement Setting Accelerators (MRDE, 1980(b))

A. PROTECTIVE CLOTHING

   1. Clean overalls shall be provided as required by the workmen concerned. Overalls shall be changed at least once per week and more frequently if necessary.

   2. Rubber boots shall be worn.

   3. Waterproof overtrousers shall be worn over the rubber boots to prevent the ingress of cementitious or other materials in to the boots.

4. A waterproof overjacket shall be worn which can be fastened around the neck. A clean cloth, such as a bandage, should be placed around the neck to prevent friction between the overjacket and the skin. This cloth shall be washed daily, or replaced.

5. Long gauntlets of waterproof material shall be worn.

6. A dust respirator which complies with BS 2091 shall be used.

7. Eye protection shall be worn by the nozzleman and any person working in the vicinity of the nozzle while spraying is taking place. The eye protection can be in the form of goggles or face screen and must comply with BS 2092 - Impact grades 1 or 2.

8. Barrier cream shall be made available as an individual issue to each workman.

B. FIRST AID

1. Individual eyewash bottles as issued by the Colliery Medical Officer shall be carried by all operatives when spraying is taking place.

2. In the event of caustic materials coming into contact with the skin, the affected part must be washed thoroughly in clean water as soon as possible. A water supply and containers shall be conveniently placed for this purpose.

C. OPERATIONAL PRECAUTIONS

1. No part of the shotcreting machine or auxillary hoses shall be disconnected unless the air supply to the equipment is at first isolated.

2. Before opening the accelerator dispenser, the air pressure in each compartment must be relieved using the valves provided.

3. Empty cement bags and any accelerator containers used shall be removed from the mine at the end of each shift.

4. Accelerators must be approved for use underground, or covered by a Letter of Exemption.

10.3 Problems Associated With Pneumatic Stowing

Dust

In pneumatic stowing, significant amounts of respirable dust can be created when fine particles of stowing material are projected by a high velocity airstream. This float dust, particularly particles smaller than 5 microns, can constitute a health hazard in the immediate working area. Methods exist for reducing dust, however. They include injecting water into the discharge stream of particles, wetting down the material before it is placed into the stowing hopper, and reducing the airflow to the minimum necessary for transporting material through the stowing pipe. Dust control is the most serious problem associated with pneumatic stowing, particularly when stowing is done in proximity to sections that are being mined.

Noise

Noise produced by most pneumatic stowers typically exceeds the desired 90 kbA (over 8 hours) sound level, with sound levels of 109 dbA at the blower, 103 dbA at the feeder, and 107 dbA at the end of the blow pipe. Personnel working with equipment at these soundlevels would have to reduce their exposure time accordingly. Significant reductions in sound levels can be achieved by shrouding the stower and blower with acoustical materials and by fitting a silencer on the airline between the blower and the stower. Reductions in sound level readings were not so dramatic in confined levels underground as they were on the surface, and the 90 dbA level was not achieved despite the noise reduction measures. However, the noise levels of a low pressure stower ranged from 83 dbA at the blower inlet to 87.5 dbA at the blower outlet. Still, the noise level at the discharge pipe outlet was 100 dbA.

Traditionally, underground coal miners have used "roof noises" as warning signals of impending roof falls. It has been stated that the additional noise created by stowing equipment would diminsh with the miner's ability to hear roof noises--noises that have been measured in the 70-80 dbA range. But typical mining machinery produces noise far in excess of this range (95 - 115 dbA); therefore, roof noises probably could not be detected any way if the stowing were done in proximity to mining operations. Ear muffs and ear plugs provide partial solutions to the noise problems, but miners resist using them, citing discomfort and the inability to hear roof noises as reasons.

Sparking

There has been concerns expressed in the industry of danger of methane ignition resulting from sparks that are produced as particles strike a rock surface after being expelled at high velocity from the stowing nozzle or from sparks resulting from charges of static electricity that are built up as particles rub against each other in the transport tube. No ignitions of gas attributable to pneumatic stowing have been recorded.

APPENDIX 1

DSS File No.: 07SQ.23440-5-9009

NON-COMBUSTIBLE REPLACEMENT MATERIALS, METHODS AND TECHNIQUES TO REDUCE THE USAGE OF WOOD IN UNDERGROUND COAL MINES

REQUIREMENT

On behalf of the Department of Energy, Mines and Resources to complete by December 30, 1985, a review into available materials, methods and techniques that could be used effectively and beneficially in the place of wood as a support and construction material within Cape Breton coal mines. A particular emphasis must be placed in the review on the possibilities of using materials that can be obtained from sources within Cape Breton and the Maritime provinces.

BACKGROUND

Timber and lumber were the first support materials to be used within mines. The use of wood was not originally considered to be a hazard in the mining environment as the industry was labour intensive and the tasks were mostly accomplished by persons using hand tools. Machines and machinery were not greatly in evidence and the early power source for the use of machinery within coal mines was mainly compressed air. Progressikve advance in mining technology has seen the introduction over the last quarter of a century of sophisticated and complex electrical, mechanical, and hydraulic plant and machinery into the coal mining environment.

Such plant and machinery has raised the potential sources for ignitions from a few to many. Mine fires that have assumed disastrous proportions and have caused in some cases serious loss of life, can be attributed to the spread of fire throughout major sections of such mines. The agent for propogation of extensive fire zones has been an abundant presence of wood for either the purpose of support covering or construction. The closure of No. 26 mine of the Cape Breton Development Corporation was the result of such a fire zone.

Endeavours have been made in many countries to counter the potential for serious fires in underground coal mines. The U.K. National Coal Board has opted for the fire retardant treatment of timber. This scheme, though costly, has had only partial success in the prevention of the propogation of fires.

The W. German mining industry has made considerable progress with an over all reduction in the usage of wood by 92% during the last two decades. This has been spurred by two considerations, the need for economy, and the demands of safety. The need for economy has been dictated by the depletion of indigenous resources of wood, and the need for safety is dictated by the working of coalfields that have high liabilities to spontaneous combustion and a serious history of fires.

There are places in a mine where the risks associated with the use of wood are small and the benefits are great. Such places should not be denied the benefits of the use of wood.

STATEMENT OF WORK

PHASE I

1. To develop a rational framework such as the U.S. Bureau of Standards Fault Tree Analysis System from which an assessment will be made of the relative fire risks that are encountered in various parts and places of the undersea workings of coal mines that are operated by Cape Breton Development Corporation. The assessment must take into account as a minimum the following:

STATEMENT OF WORK (Cont'd.)

- i) The numbers and frequency of persons working in and passing through such placed.
- ii) The type of machinery, plant, and equipment in such places.
- iii) The possible ignition sources/mechanisms.
- iv) The materials and methods of construction that are applicable, and the support of the roof, sides, and if necessary the floor appropriate to such places.
- v) Open or concealed fires.
- vi) Ease of personnel evacuation and direct fire fighting.
- vii) Ease of early detection by remote and/or on-site means.
- viii) Risk of methane/coal dust accumulations.
- ix) Anticipated rates of propogation/development of open or concealed fires.

2. To review non-combustible alternatives and substitutes to the use of wood in such places. The review must address an order in the use of such substitutes and alternatives from those places with the highest risk to those with the lowest.

PHASE II

1. To examine the potential for the use of local materials and resources of Cape Breton and the Maritime Provinces for the production of substitutes and alternatives to wood.
2. To estimate the comparative operating, material, and if appropriate repair costs of the substitutes and alternatives in their fields of application.
3. To identify any health and safety risks associated with the above described alternatives and substitutes and prescribe suitable safeguards.